SOME ASPECTS OF THE PERCH POPULATION OF COBBINSHAW RESERVOIR, SCOTLAND AND ITS FEEDING RELATIONSHIP WITH BROWN TROUT

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TO IVONE, CLARISSE

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ABSTRACT

The present investigation deals with a population study involving age-structure, growth and food of perch (Perca fluviatilis L.) from an upland feeder reservoir stocked with brown trout (Salmo trutta) and the feeding interactions between these two species.

Assessment of plankton and bottom fauna was carried out in order to relate their availability as food for these two species.It was observed that the zooplankton was characterized by presence of a large numbers of rotifers and crustaceans (mainly Daphnia hyalina and Cyclops strenuus).

The bottom fauna is very rich and characterized by large numbers of trichopteran larvae, Gammarus pulex, Asellus aquaticus, gastropods and bivalves.

The investigation was complemented by some limnological studies of the reservoir which demonstrated that, in the summer dissolved oxygen and water temperature sometimes approached lethal levels for young trout being reared in cages in the reservoir. These conditions were accompanied by the presence of blue-green algal blooms. The pH varied from 7.5 to 8.5 and alkalinity (maximum 50 ppm) showed levels considered below the optimum for trout.

There was a predominance of foür-, five- and six-year-old perch, with a sex-ratio of 1.2 males:1 female. Fast growth occurred until the fourth year after which the

rate decreased, following the von Bertalanffy model.

Perch fed mainly on _Gammarus pulex_, _Asellus aquaticus_, _Daphnia hyalina_ and chironomid larvae and pupae. Trout exploited many of the same organisms. However some of the particularly important food-items for trout (trichopteran larvae, winged insects and molluscs) were rarely eaten by perch. Perch fry proved to be a very important food-item in the trout diet in June.

Differences between the food of trout and perch suggested that a segregative interaction might be occurring. However, stocked trout often show atypical behaviour and this study has provided no firm evidence to support the contention that competition between perch and trout is actually occurring in Cobbinshaw Reservoir.

Finally, a brief study of the food of pike (_Esox lucius_) was made - this is the only other fish species in the reservoir. It was observed that their diet consisted mainly of trout and perch, the former being the more important (86.32% of the total food volume),which makes it clear that pike, as a voracious predator of trout, are undesirable in Cobbinshaw Reservoir.

I GENERAL INTRODUCTION

I.1 Approach of the present investigation

Recently the number of man-made lakes has increased considerably. As such lakes can support fish populations which may form the basis for new fisheries, they have been exploited for this purpose.

In Europe, particularly in Great Britain, a large number of reservoirs has been invaded by perch. As this fish is very fecund it constitutes a problem for fisheries managers interested in stocking such lakes to provide sport fisheries. This situation occurs in lakes that support a large number of perch and are also used as trout fisheries. In this case the growth and number of trout may be affected because adult trout and perch are potential competitors (Thorpe,1974). This situation is investigated in the present work, particularly aspects of the feeding relationship between perch (*Perca fluviatilis* L.) and trout (*Salmo trutta* L.) in Cobbinshaw Reservoir which is a lake constructed for supply purposes and subsequently developed as a sport fishery. Pike (*Esox lucius* L.) are present in the lake as well, and, as they play an important role as predators (Wheeler, 1969), their effects on perch and trout have also been investigated.

The food and feeding habits of trout, perch and pike have been studied in detail, but there has been little work on this subject in Scottish waters, particularly in a situation such as Cobbinshaw Reservoir, which comprises an enclosed artificial environment where trout, perch and pike are the only fish species and the trout represent a later introduction.

The literature shows that pike,perch and trout have a very close feeding relationship and as this situation had not been investigated in Cobbinshaw Reservoir, this water was chosen as the site of the present work. The problems concerning the feeding of fish have an enormous significance in fish management. According to Nikolsky (1978) the improvement of our knowledge about the food supply will help us in understanding the basic problems in the fishing industry, such as the rational cultivation, the improvement in food conversion, the acclimatization projects, and the construction of rational methods of exploiting a stock of commercial fish. Considering that the feeding habits change from younger to older fish, the study of age and growth is included in the investigation as well.

I.2. Cobbinshaw past management

The lake was built in 1820 to supply water to the Union Canal which served industries in Edinburgh. The reservoir is divided by a causeway into a large, lower lake and a small upper lake. They are connected by culverts located underneath the earthwork enbankment that supports the causeway. The absence of tributary streams prevents natural recruitment to the trout population.

In 1905 the reservoir was leased by a private club - Cobbinshaw Angling Association (CAA) - as a trout fishery. One year later, a stocking programme of brown trout was started with 2000 one-year-old and 1000 two-year-old fish being stocked following the removal of 337 pike.

In 1907 there was an apparent complete kill of fish due to pollution in the form of run-off water from the adjacent mine owned by Tabrax Chemicals, and in 1909 the lake was restocked with 53000 yearlings, one and two-year-old trout (Boyd, 1975).

Armistead (1915) pointed out that the retention of spawn by Cobbinshaw female trout could affect their rate of growth, but it was probable that the health of the fish was not much impaired. Then, he suggested that any practicable way to enable the fish to get rid of their spawn which could be achieved at a reasonable cost would be worthwhile. Thus the construction of a stream with half-a-dozen long shallow pools and a prepared gravel bed was advised. Water for this stream was to be supplied from the lake by means of a windmill pump. There is, however, no record of the construction of such an artificial stream.

In 1933, a Sub-Committee was set up by members of the CAA to investigate stocking and Young et al. (1934) produced a report in which they stated: 'a stocking with 10,000 yearlings must be sufficiently large as to be adequate even on the worst view which may be taken as to wastage due to there being pike and perch in the lake'.

Several pages of the report were devoted to discussing whether to stock the lake with yearling or two-year-old trout, its financial implication and the advantage of using Cobbinshaw trout ova in exchange for yearling fish from Howietoun Fisheries. At the time it was not difficult to get as many ova as required by netting trout and the Sub-Committee assumed that the ill-effects to the small proportion of the trout which retained their ova were not serious enough to warrant adoption of Armistead's (1915) plan.

The causes of loss and wastage of trout in the lake were identified by Young et al. (1934) as:

1- Escape at the west end and sluices end of the lake. However, there was evidence that this loss was negligible.

2- Cannibalism: the stock included trout of different ages and sizes and it must be supposed that a great many trout were lost through cannibalism, particularly the yearlings.

3- Predation by pike: it was recorded that 139 pike were killed in 1933 and 197 in 1934 and it was concluded that the number of large pike in the larger lake was considerable and since 'pike feed on trout at a rate of its own weight' a programme was proposed for capturing pike using various methods - this proved to be unsuccessful.

4- Presence of perch: 370 perch were killed in 1933 and 41 in 1934. It was stated that the average size of perch in the small lake was much larger than the average size of those in the large lake. It was considered that this was due to the pike being much more numerous in the small lake.

Attempts to take perch from the large lake in 1934 by means of wire perch traps, were unsuccessful

In 1940 the Association proposed preventing the passage of fish from the small lake - a good environment for perch and a poor one for trout - to the large lake. Ronald(1940) suggested that the plan was not convenient and provided evidence of how it could cause 'the flooding of the surrounding low-lying land and damage the embankment and roadway.' The proposals were abandoned.

From 1944 to 1949 there was a decline in the number of trout caught. Steven & Cross (1949) suggested that 'the trout decline was certainly related to the increase in the number of perch, because both species compete for food (freshwater shrimps, snails and larvae of insects).' Thus, trout growth was slow and they became an easy prey for pike. At the time the following ratios were recorded: two perch for every trout and one pike to approximately every fifty perch and trout. Pike influence on the trout population was not considered very important as pike kept the same average population over the past 40 years and they preferred the smaller and more easily caught perch to trout. Finally, re-examination of the question of isolating the lakes and a drastic reduction of perch (by trapping) and pike (by netting) was recommended before setting-up an extensive stocking programme. Cross & Steven (1949) intended to reach a stock of about '10000 trout (40-50 takeable trout per acre) and a yield to anglers of 10 lbs of fish per acre per annum (about 12 fish per acre)'. These figures were comparable with the average annual yield for Loch Leven (Scotland), a very productive lake at the time.

Malloch (1949) agreed with Cross & Steven (1949) in relation to the stock the lake was capable of supporting but disagreed in relation to the cause of the trout decline. He suggested that the perch did not influence trout growth and pointed out the importance of the fry of perch as food for the trout.He concluded that pike population was the main factor affecting trout population. This conclusion was supported by comparing Cobbinshaw fish-stocking with similar situations in Loch Tummel, Loch Tulla, Loch Leven and Loch Rannoch. It was also stated that the high altitude and exposure of the lake could interfere with the duration of trout feeding and consequently growth. Finally, intensive netting with a view to eradication of pike was recommended. This plan was put into practice and there was a most satisfactory improvement in catches until 1958. At that time the stocking policy changed from 1000 yearling to 5000 two-year-old a year.

In 1958 there was a tremendous decline in the trout catches. This situation was pointed out by Mr.R.N.Campbell in 'Conversation with the Secretary of the Association' (Boyd,1975) as a consequence of another increase in the numbers of pike and perch. An intensive pike and perch netting, removal of all netted trout over 1kg and no stocking in 1959 was recommended. At the time the rotenoning of the small lake was suggested but it was not adopted because of the risk to the trout in the large lake.

In 1970 the lake was restocked with 9000 fish.

Boyd (1975) made a general description of the reservoir, a summary of the past history of management, an outline of the life history of the fish and some recommendations for future management. He concluded that the reservoir had a good water quality and a rich bottom fauna, although insect larvae were scarce. The perch population exhibited fast growth to 28 cm but then became stunted. A relation between pike captures and trout returns was observed.

Burns (personal communication) started in 1979 an investigation on the population dynamics, growth and performance of Cobbinshaw trout. His aims were to study growth of individual fish, movements during the year and the effects of angler's performance on the population structure. There are no published data on his work.

Proctor (1980) discovered a predominance of six-year-old pike in Cobbinshaw with an average length of 50 to 55 cm. Growth of Cobbinshaw pike was considered slow when compared with that of Rosebery Reservoir (Scotland), Windermere (England) and Lough Glore (Ireland).

More recently, the reservoir has been stocked annually. Younger fish are placed in rearing cages in the centre of the reservoir before their release in the autumn. Fish in these cages are fed with unpigmented high density pellets (Edward Baker-Omega).

I.3 Objectives of the work

In reviewing the literature of Cobbinshaw Reservoir one could see that all the works refer to the fisheries management and take little account of the lake itself. The majority of the observations were carried out in order to investigate the influence of the number of perch and pike upon the trout population and the main source of data is the CAA fishing log book. It is possible that the decline in number of trout, perch and pike catches recorded could be related to the weather conditions and methods used to capture the fish. However, this kind of information is not available. Few of the studies refer to the limnological aspects of the lake and the availability of natural food organisms. All the works mentioned treat the subject very briefly and there are no data to support the conclusions.

Boyd (1975) recommended a regular monitoring of the stomach contents of captured fish throughout the season before a conclusion could be made about the diet of Cobbinshaw trout. Thus it is clearly necessary to have more information about the lake and about the feeding relationship of perch, pike and trout in order to improve trout production.

Recent records show that the numbers of pike have declined, but perch catches are still very high (Appendix 1). As perch feeding habits may affect trout growth the present work concentrates on the study of the perch population and the main aims were:

- to study some limnological aspects of Cobbinshaw Reservoir in order to make an assessment of the water quality.
- to study the age, growth and food of perch.
- to make an assessment of the availability of invertebrates used as fish food.
- to study the feeding relationships of perch, trout and pike.

A study of numbers of trout, perch and pike was, initially proposed but the Association would not give permission for the use of the techniques necessary in such a study.

I.4 **Perch Biology**

I.4.1 **Morphology and systematics**

According to Collette & Banarescu (1977) the Eurasian or European perch (*Perca fluviatilis* L. 1758) is one of the 163 species of the order Percidae, sub-family Percinae, Tribe Percini.

The principal diagnostic characteristics of the Percidae are the separation of the two dorsal fins, the presence of more than nine rays in the anal fin and of more than 50 scales along the lateral line. This family differs from most other percomorphid families in having a single or no predorsal bone instead of two or more. The Percidae appear to have originated from some anadromous basal percomorphid family during the Cenozoic in Europe (Collette & Banarescu, 1977). According to Maitland (1972) the main characteristics of Perca fluviatilis are (a) the base of the first dorsal fin is longer than that of the second, (b) there are less than 70 scales along the lateral line, and (c) only short teeth are present in the mouth.

The name perch (greek = perki, latin = perca) means the dusky colour of ripening grapes and refers to the banded marking of the body (Thorpe, 1977b).

P. fluviatilis has an equivalent form in America - the yellow perch (Perca flavescens M. 1814).By comparing biological characteristics of the two forms, Thorpe (1977b) concluded that they were biologically equivalent and Collette & Banarescu (1977) showed that they differed in the position of the predorsal bone and regarded this sufficient to recognize them as separate species.

P. fluviatilis and P. flavescens are very well-known fish and their biology and ecology are discussed comprehensively by Thorpe (1977b) in a synopsis of biological data on the two species.

I.4.2 **Environment**

Usually perch inhabit ponds and lakes, but they also occur in slow rivers and streams. Young fish are more common in the shallow areas of lakes close to the shore than are adults (Wheeler, 1969).

According to Collette & Banarescu (1977), Percidae are limited by high temperature and are adapted to the temperate climates of the northern hemisphere. However, they can be found in temperatures of about 30°C in the southern hemisphere. The physiological optima of perch vary from 22°C to 28°C and a salinity of up to 10‰ can be tolerated. Perch occur naturally throughout Europe and North America but their occurrence in South Africa, Australia and New Zealand is entirely due to introductions (Thorpe, 1977b).

I.4.3 Reproduction

Hokanson (1977) stated that percoids are characterized by a long annual reproductive cycle. Perca fluviatilis spawns between February and July in the northern hemisphere and between August and October in the southern (Collette et al., 1977), but spawning-time can be modified by changes in temperature: gamete maturation, spawning, embryo and larval development and commencement of independent feeding by larvae have successively higher thermal requirements.

Data on the sex-ratios are widely divergent between localities studied but this is often because of sample size and gear selectivity (Thorpe, 1974). Individuals show sexual dimorphism. Usually females are larger than adult males of the same age, and gravid females have a swollen appearance and slight protusion of the genital orifice. Hermaphroditism is not common. However, it was reported by Chevey (1922) and Turner (1927).

Maturity occurs first in males (between 5 and 16cm) and growth-rate influences maturation in both sexes (Alm, 1953, 1959). Females have a single ovary, which differs enormously in weight before and after spawning: Le Cren (1951) recorded variation from 1% of the body-weight in July to 23% in April.

Normally, several males follow the females to the spawning area, mostly in water from 0.5 to 3m deep (Fabricius, 1956; Harrington, 1947; Hergenrader, 1969; Jones, 1982). The females lay their eggs in one continuous connected strand which is immediately fertilized by males, who shed a cloud of milt close to the egg-strand. The number of eggs ranges from a few thousand to 500,000, and egg diameter from 1.0 to 2.0mm (Thorpe, 1977b).

Competition for spawning areas is not an important factor in Perch biology since their site requirements are not restricted (Thorpe,1977b). Spawning has been recorded at night (Scott & Crossman, 1973) and by day (Chevey, 1925).

Usually, most of the larvae hatch seven days after fertilization at a mean length of 5.6mm with a maximum yolk diameter of 0.9mm and an oil globule of 0.5mm (Thorpe, 1977b).

I.4.4 Growth

According to Guma'a (1978c) the growth of larval perch is characterized by two stanzas: one during metamorphosis and another which starts after metamorphosis and continues until the end of their first year. At the end of their first year of life their average length is 7cm and 11cm at the end of the second year. They can grow to a maximum length of 50 cm (Tesch, 1955) and can reach weight of 10 Kg as has been recorded in Australia (Lake, 1959). Le Cren (1958) noted that there was no difference in the growth-rate, of males and females, during the first two years of life in Windermere, but subsequently females grew slightly faster than males. Three-and four-year-old adults had a constant annual increment in weight regardless of age. This finding suggests that the growth of perch can not be described by the von Bertalanffy curve (1938) in which the rate of growth declines as the fish approaches its maximum size. However, Craig (1980) showed that the von Bertalanffy growth model fitted well the growth data for perch and suggested that the growth pattern varies in different localities.

The growing season is usually from June to October (Le Cren,1958; Cobble, 1966). During overwintering growth is retarded because the fish stop feeding and utilize their accumulated fat reserves (Nikolsky, 1978).

The amount of fat reserves in the internal organs is variable. According to Morawa (1956), in perch about 20cm long the greatest amount occurs in the body-cavity and this is the site where there is greatest variation during the year. The second greatest accumulation is in the tissues of the head. The muscles contain the smallest amount of fat and here there is little variation thoughout the year.

Perch exhibit strong year-to-year variation in year-class-strength. Thus, age size and weight composition vary widely in different localities.

I.4.5 **Food and feeding habits**

Young fish feed on ciliates, algae, rotifers, cladocera and cyclopoid nauplii (Guma'a,1978a). As the fish grow they change their diet from zooplankton to insect larvae and larger invertebrates. They become piscivorous after different periods of time. Although piscivorous fishes seem to show some preferences for species or size of prey, the wide variety in diet shows that availability is more important than preference. Prey-size rarely exceeds half the length of the predator and usually is considerably less than that (Biro,1977; Willemsen,1977). The size at which fish become important in the diet of perch varies between 10 and 15cm (Hartmann & Numann,1977; Hölčik,1977; Rundberg,1977; Willemsen,1977; Popova & Sytina,1977).

Cannibalism occurs frequently among Percomorphi if the food supply is inadequate and may then even reach a level where their own kind forms the main food resources, in many cases resulting in self regulation of the stock (Forney,1971; Chevalier,1973; Biro,1977; Hölčik,1977; Nagięć,1977; Popova & Sytina,1977).

Usually, feeding is very intensive in the summer and either reduced or absent in the winter. However, Scott & Crossman (1973) observed active feeding in yellow perch during the winter.

Feeding activity of perch is related to adaptation to low light intensities, often leading to two main feeding periods, in the early morning and evening. Fingerling perch during the plankton-feeding stage show two peaks in activity (early in the morning and in the evening), but during the benthos-feeding stage they feed only in the morning (Spanovskaya & Grygorash,1977). In adult perch a frequent pattern of mid-morning and evening peaks of feeding activity may sometimes be marked, especially among piscivorous individuals, by the irregularity of prey availability (Thorpe,1977a).

Food consumption depends on temperature and food-supply (Swenson,1977). The daily ration varies from 3.7% of the body-weight (Popova & Sytina,1977; Thorpe,1977a; Swenson,1977) to 11% (Willemsen,1977) in predatory perch during the growing season, whereas in plankton-feeding fingerlings it can reach a level of 28% (Spanovskaya & Grygorash,1977). Perch consume annually at least 220% of their body weight (Popova & Sytina,1977). Food conversion in optimum feeding conditions is 4-5.5 to 1 (Popova & Sytina,1977; Willemsen,1977).

I.4.6 Migration

Perch generally do not move great distances. The main annual pattern is migration during the period before spawning towards the spawning grounds, and after spawning, a gradual dispersion over the feeding area. Onshore spawning migrations in the spring may be guided by temperature gradients in the direction of optimal temperatures for gamete viability and embryo survival (Rawson,1957; Belyy,1963; Forney,1967; Priegel,1970).

Although distances of 70km can be covered, perch maintain a preference for their 'own' area of the lake. This limited migratory behaviour may even lead to different morphological groups within the same lake (Chikhova,1973). Vertical migrations are common as a result of avoidance of high light intensity and low temperature but are generally of only diurnal duration (Collette et al.,1977).

Usually, perch migrate in shoals of 50-200 individuals (Hasler & Bardach,1949), which are stratified by sex, age and size (Hartmann,1974).

I.4.7 Mortality

According to Thorpe (1977b) 'Values of total annual mortality of adults appears to range normally between 45-70%'. Hölčik (1969) noted that in Klicava reservoir (Czechslovakia) males showed a higher mortality rate than females. Thorpe (1977b) pointed out that among the main factors affecting or causing mortality are predators (particularly birds and fish);parasites(Bacteria,Fungi,Protozoa,Trematoda, Cestoda, Nematoda, Acanthocephala, Hirudinea, Mollusca and Crustacea); lack of food at larval and post-larval stages and physical factors, such as exceptional meteorological conditions, and fishing.

II. CHEMICAL AND PHYSICAL CHARACTERISTICS OF COBBINSHAW RESERVOIR

II.1. Introduction

The aim of this chapter is to provide a preliminary survey of the physical and chemical characteristics of Cobbinshaw Reservoir in order to establish a relationship between water quality and the requirements of perch and trout. The data are also compared with those from other investigations and with the reports on water-quality criteria for freshwater fisheries established by the European Inland Fisheries Advisory Commission (EIFAC) and discussed in Alabaster & Lloyd (1982).

According to these authors establishment of water criteria necessary for fish production is essential, particularly when there is some degree of pollution. They described water quality criteria for fish as the relationship between the concentration of the water quality characteristics and the response of the organism.

Hellawell (1978) showed how difficult it is to define water quality as it is a very subjective concept and recommended that the purpose for which the survey, or monitoring, is required should be clearly defined.

Naturally, it is not possible to define the total characteristics of a freshwater environment only by describing some physical and chemical parameters, but this part of the appraisal of water resources may lead to an estimation of its potential.

Most chemical and physical parameters are directly involved in the life of freshwater organisms and some of them are very closely related to fish ecology, particularly, light penetration, pH, alkalinity, turbidity, dissolved oxygen, carbon dioxide and water temperature. All these parameters were measured in the present investigation and analyses were also extended to nitrogen, phosphate and silica.

II.2 **Water level**

Materials and methods

Water level was taken weekly using a graduated wooden scale placed on a concrete wall on the bank. The first record was taken in February when the depth in the area was 90cm.

Results and discussion

Fig.II.1 shows the variation of water level from February to November 1982.

The results show, at least for 1982, that there is a seasonal variation of more than 80cm in water level, probably related to the melting of ice and snow in spring, low precipitation and high evaporation rate during the summer and greater precipitation in the autumn.

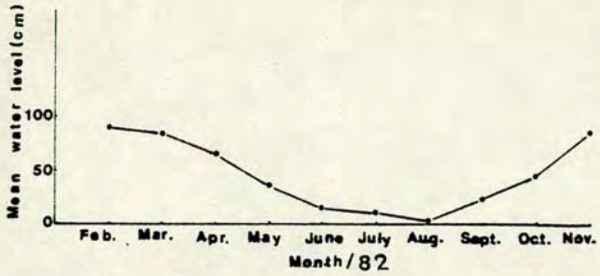


Fig. II.1 - Monthly variation of the water level

Naturally, lowering of water level causes partial exposure of the littoral area. As shown in a later chapter this area is the most important feeding area for fish in the lake, and its exposure causes a decline in the availability of food due to migration or death of the invertebrates in the exposed area. The non-exposed area of the littoral zone is represented by quite shallow and warm water: probably it is these factors which explain the migration of trout to deeper and colder water (See page 37)

Two aspects, which are discussed in further chapters, may be used to support this statement. The first is the predominance of food items from deep water in the trout diet and the second is the large number of perch caught in shallow water with a seine net as against a very low number of trout.

The lowering of water level coincides with the flowering and emerging of weed-beds. In a south-east and in a south-west bay there is a complete exposure of Equisetum palustre and Caltha palustris. However, Potamageton natans stems and roots are always submerged. Plate I, illustrates this situation.

Compared with other waters, Cobbinshaw is quite a shallow reservoir (Fig.II.2). As shown in Fig.II.1 the lowest water level was recorded in the summer. At this time the water near the shore was warmer than in open water. It was observed that at this time shoals of perch-fry were common in the former.

By the end of September the water became colder and the water level was higher than in the summer. At that time trout started moving towards the shore and perch had an inverse migration. In early winter the littoral area (from the bank to about 2m deep) became frozen and in January it froze to quite a depth, which suggests that all the fish migrated to the deepest area.

Results showed that variation in water level combined with that of water temperature are important factors affecting Cobbinshaw Reservoir fish populations. However, fish spawning behaviour must be taken into account.

II.3 Bathymetric survey

Materials and Methods

Soundings of the lake were carried out by hand using a graduated rope with a weight at the end. The weight was lowered very slowly until it touched bottom. Then the depths were recorded. In order to establish sounding position a trout-rearing cage placed in the centre of the lake was taken as an initial point and transects were traced from the cage to reference positions on the bank and the soundings were made along these transects.

Results and discussion

Fig.II.2 shows the bottom topography of the lake. Because of the presence of mud (peat-ooze) the exact depth in areas over 2m is not very accurate as the weight probably sinks into the soft bottom. However, the map gives a clear idea of the bottom topography.

Soundings were carried out in July, when the water level was very low (14.5cm at the scale). At this time the maximum depth was about 4.5m. However, in December when the lake was completely full a maximum depth of 6.5m was recorded.

Variations in depth in different periods of the year may affect fish behaviour. Trout spawn between October and February. At this time internal factors such as ripening of gonads and the gonadial hormones determine migratory behaviour (Frost & Brown, 1972).

Usually, trout living in lakes move to feeder streams in the spawning season. As there are no streams flowing into Cobbinshaw Reservoir presumably they move from the deeper sub-littoral area to the shallow stony wave-washed shore of the lake, which resembles the gravel banks of running waters. According to Frost & Brown (1972) they may spawn in such an environment. The presence of some dead trout eggs among the bottom fauna collected in a gravel area suggests the occurrence of trout spawning in Cobbinshaw Reservoir.

Perch, on the other hand, occupy deep water during the winter and move to shallow water in spring, remaining there until the autumn (Thorpe,1977b).

Such observations on perch and trout spawning behaviour combined with the results obtained in Cobbinshaw Reservoir suggest that in this lake perch and trout do not co-habit the same area, particularly in the spring, summer and autumn.

There are different observations concerning the depth distribution of perch. Jones(1982) found that in Loch Leven (Scotland) spawning may take place between 1m and 5m and showed evidence that depths around 3m are preferred. Stone (1944) recorded yellow perch from 28m in August to 56m in November in Lake Ontario (Canada).

In general, the literature shows that substrata between 3m and 5m are a very good habitat for perch and that perch distribution in different depths is related to lake topography and water quality. The older the fish, the more likely it is to be found in deep areas in a lake (Hasler & Wisby,1958).

Varley(1967) distinguished deep lakes as typically salmonid waters and shallow lakes as cyprinid waters. In this classification Cobbinshaw Reservoir represents an intermediate depth lake suitable for mixed populations, with predominance of pike and perch.

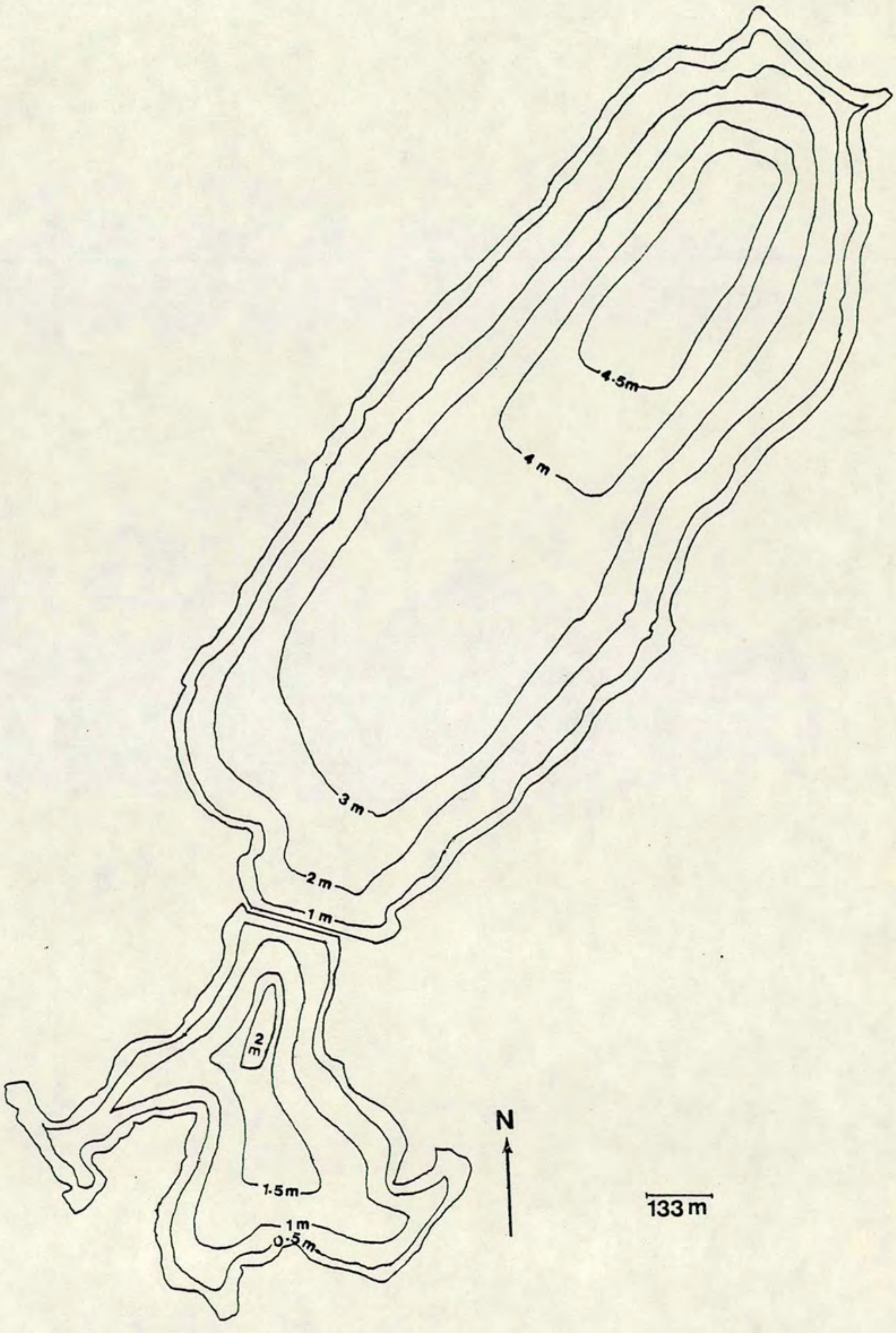


Fig. II.2 - Bottom topography of Cobbinshaw Reservoir.

II.4 Transparency

Materials and Methods

Transparency was measured with a Secchi disc (Welch, 1948), which comprises a circular metal plate 30cm in diameter with an upper face divided into four quadrants painted alternately in black and white. A weight fixed at the lower face facilitates the sinking of the disc and a graduated rope is used to lower it into the water. The use of a freshwater secchi disc consists in lowering it into the water until it disappears and in lifting it until reappears. The average of the depths at which it disappears and reappears is considered the limit of visibility or transparency.

Results and discussion

Fig.II.3 shows the water transparency at monthly intervals from February to November 1982. It varied from a minimum of 50cm in February reaching a maximum of 165cm in July and then declined again to November. These results show that Cobbinshaw Reservoir transparency has an adequate level all the year round, as the very productive littoral area extends only up to 2m.

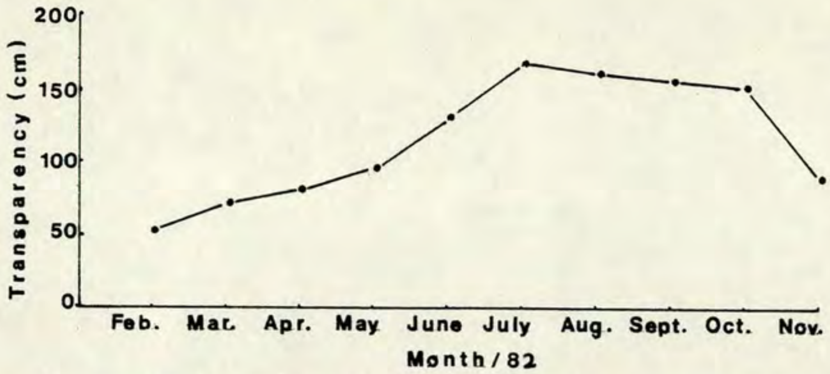


Fig. II.3 - Monthly variation of water transparency.

In the summer the water was more transparent than in other seasons. Presumably, this is due to reduction of suspended material as a consequence of lack of natural circulation and lack of strong winds mixing the water. Furthermore, in the summer the total solar energy received by the water surface in this latitude reachs its maximum value (Hutchinson,1967). However, it must be mentioned here that weak winter and autumn sun associated with adverse weather conditions could affect transparency measurements.

Transparency is essentially an index of visibility (Welch, 1948) and it is influenced by suspended materials. In Cobbinshaw Reservoir the main source of such materials are allochthonous matter derived from the peat bogs , plant debris from the shallow marginal area and algal concentration.

Light penetration is very important since fish use vision in orientation, movement, food searching, etc. (Nikolsky, 1978). Peart (1956) pointed out that trout use sight to capture food but that they have good vision at low light levels. Perch, on the other hand, were classified by Wunder (1926) as a "bright-light" fish. Thus, they are day-active and spend the night resting at the bottom; this view is supported by Hergenrader & Hasler (1966, 1967, 1968).

II.5 **Bottom Substratum**

Materials and Methods

Bottom samples were collected in different stations to assess the bottom substrata. In shallow water samples were collected by disturbing the bottom with the foot and collecting it in a net. In deeper areas an Ekman grab (Hellawell, 1978) was used. It comprises a square box of sheet brass with a cross section of 22.8cm^2, with an opening closed by two strong brass jaws. Two chains hold the jaws open against two pins located on a spring mechanism at the top of the sampler. A winch fitted with a graduated cord is used to lower the grab and a messenger is sent down the rope causing the release of the chains and closure of the jaws. It is recommended by Welch (1948) as the standard instrument for soft bottoms.

After collection, the material was taken to the laboratory where it was passed through a vertical nest of sieves with mesh graded from coarsest(40mm) at the top to finest (0.062mm) at the bottom by directing a stream of tap water into the upper sieve. The material of each sieve was classified according to Herrington & Dunham (1967) as follows: Boulders (rocks over 12in (30.4cm) in diameter), rubble (3 - 11.9in (7.9 - 30.3cm), gravel (0.1 - 2.9in (0.3 - 7.8cm), sand/silt (<0.1in (0.2cm)).

During the collection of bottom material, samples of plants were collected in each substratum with a net and by hand for further examination.

Results and discussion

Figure II.4 shows the distribution of bottom substrata in the lake. The area where there is most variation and which has been studied in greatest detail is the littoral zone from the shore line to the lakeward limit of the floating vegetation. The zone has an average width of 80m and a maximum depth of about 2.0m.

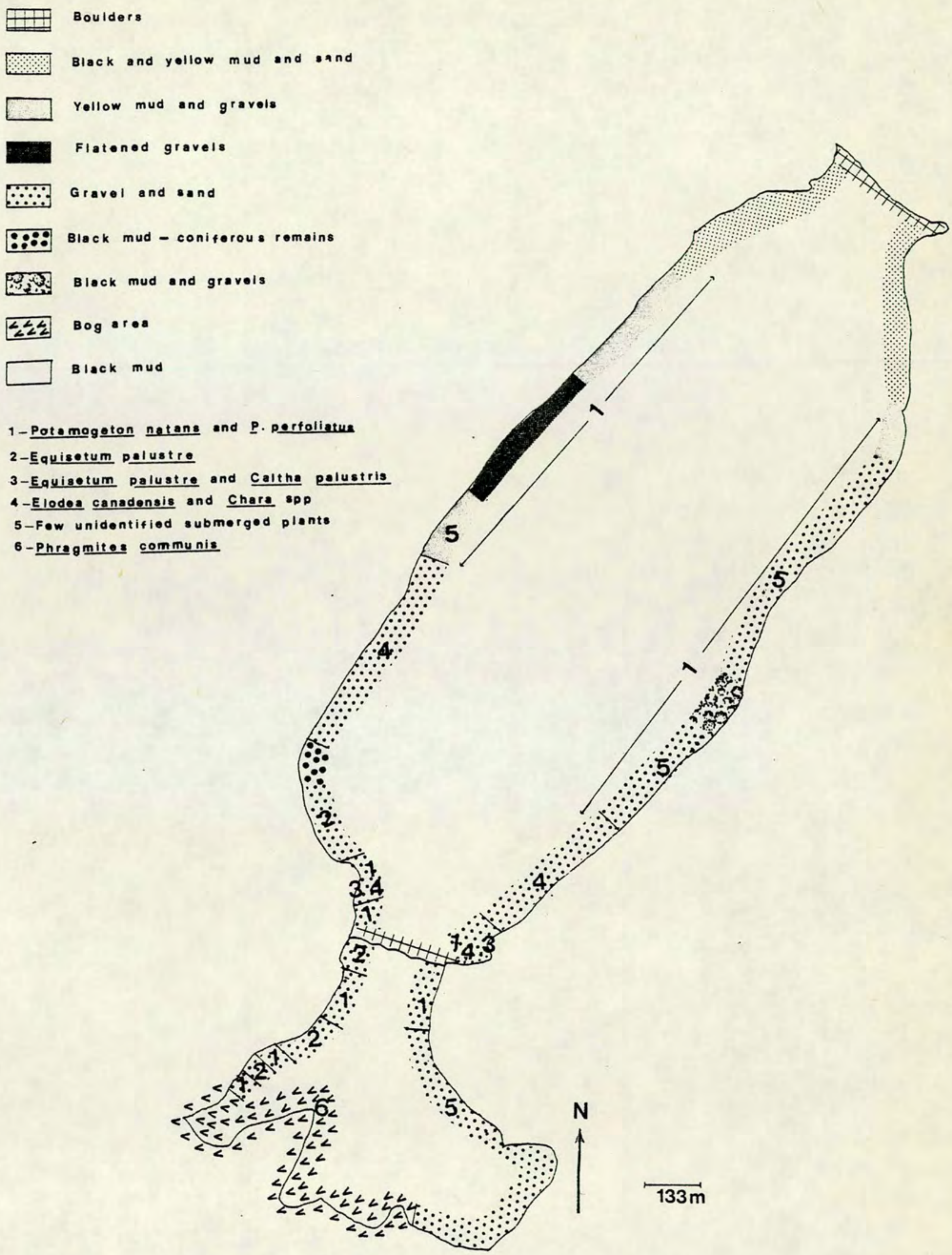


Fig. II.4 - Map of Cobbinshaw Reservoir showing the bottom substrata. Number (1-5) represents the distribution of weed beds (see text).

The substratum ranges from boulders at the dam and the causeway, through gravel and sand in most of the littoral zone to a large muddy area in the centre of the lake.

Figure II.4 (n. 1 to 5) also shows the distribution of vegetation in the lake in relation to the substratum.

Distribution of Potamogeton natans and P. perfoliatus in shallow water is shown by number 1 (Fig.II.4). Number 1 (Fig.II.4) shows two stretches of these two plants in an area about 80m far from the bank. Number 2 (Fig.II.4) shows the distribution of Equisetum palustre which in both south-west and south-east bays appears together with Caltha palustris (Fig.II.4 n.3). Fig.II.4 number 4 shows the distribution of Elodea canadensis and Chara sp, which were not recorded in the upper lake. Some submerged unindentified plants are represented by number 5 (Fig.II.4) and Phragmites communis predominant in the bog area is represented by number 6 (Fig.II.4).

Fig.II.5 shows a transverse section of the lake, along the causeway, with the distribution of emergent and submerged plants. The Equisetum palustre and Caltha palustris grow in the transition area between terrestrial and aquatic environments. Elodea canadensis and Chara sp are submerged plants at the gravel and sandy zone while the Potamogeton species grow in the deepest part of the littoral area on a substratum intermediate between gravel and black-mud.

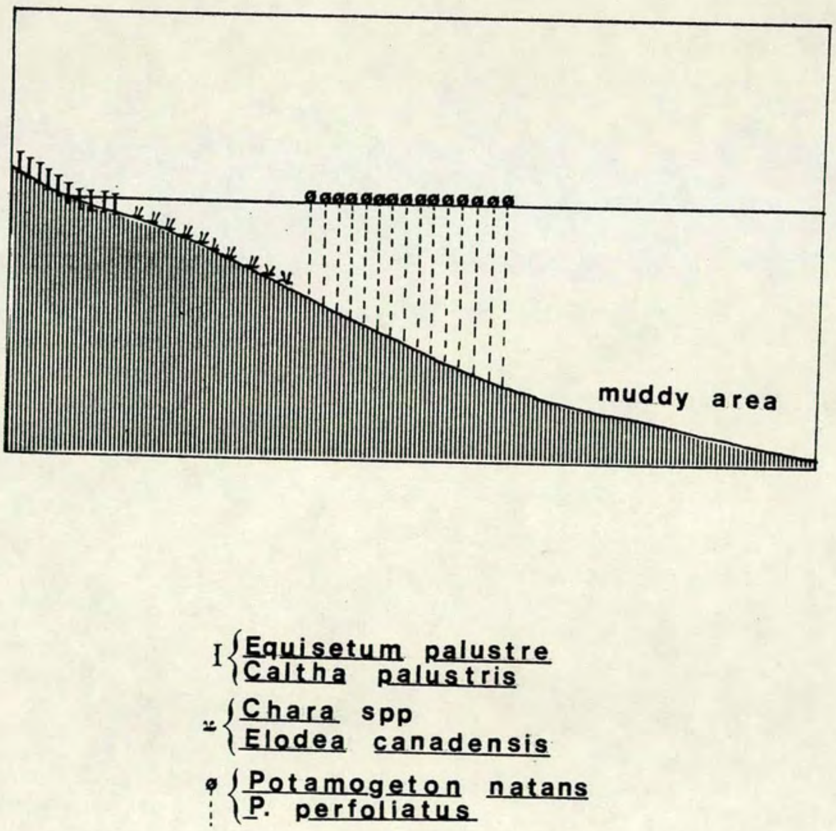


Fig.II.5 - Transverse section of Cobbinshaw Reservoir, near the causeway, showing aquatic plant distribution.

The effect of water-movement and physical characteristics of the bottom are very important in determining the type of substratum, invertebrate fauna and vegetation present. As discussed later, this zone is richer in invertebrates than deeper water and stretches within it with gravel and sand are richer than the muddy areas. The littoral zone contributes significantly to the total productivity of the lake as it supports a large quantity of macrophytes, which constitute an important source of organic matter. These plants support many species of organisms and provide spawning sites for perch and pike.

Regarding the importance of the bottom substratum to fish, Nikolsky (1978) suggested that many species never touch the bottom; others interact directly with it in feeding, spawning,etc., while yet others spend most of their life on the ground.

Varley (1967) distinguished lakes with rocky or stony shores and few rooted plants as Salmonid lakes, by contrast with Cyprinid waters with muddy bottom and an abundant growth of macrophytes.

Mills (1971) pointed out that trout potential spawning sites are characterized by the presence of water currents flowing downwards into the gravel - a condition not available in Cobbinshaw.

Scott & Crossman (1973) noted that yellow perch are most abundant in lakes with a muddy, sandy or gravel bottom. However, Hölčik (1970) demonstrated that they are very adaptable to different substrata.

Jones (1982) pointed out that presence of mud or silt down to 2.5m can inhibit perch spawning on exposed shores.

According to Varley's (1967) classification of bottom substrata, Cobbinshaw Reservoir is a kind of mixed lake which can support perch, pike and stickleback with some salmonids or some cyprinids. The large number of perch present in the lake suggests that Cobbinshaw offers an excellent site for this fish and that they are well adapted. They spawn between 1.5 and 3m, particularly on the vegetation. The substratum provides good feeding for trout, although there is no suitable site for spawning. Gill nets set up during the spawning season proved to be an adequate spawning site for perch.

II.6 **Temperature**

Material and Methods

Surface water temperatures were recorded by using a Bacharach tempscribe with bulb-type element for recording temperature on a chart.

When the chemical and physical analyses were made water temperature was determined using a thermometer.

Results and Discussion

Figure II.6 shows the mean surface water temperatures in each month from February to December 1982. They varied from ice at 0°C in January 1982 to a maximum of 25°C recorded at 6 p.m. on 6 June 1982.

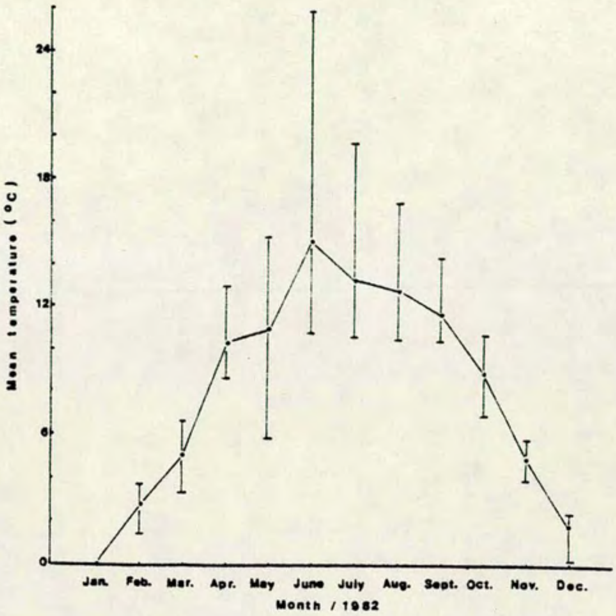
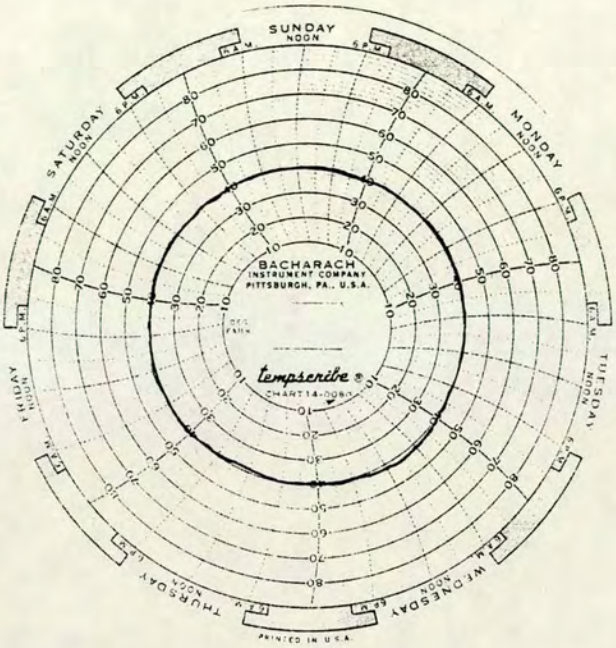
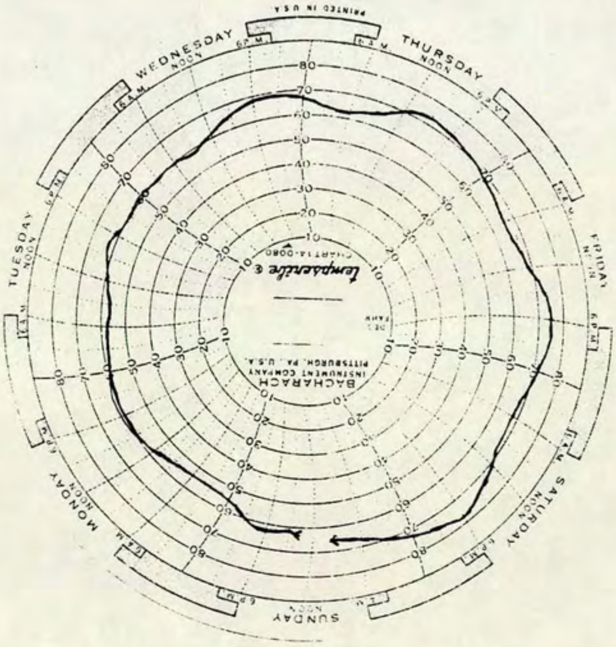


Fig. II.6 - Monthly variation in the mean surface water temperature. Bars represent temperature ranges.

It was observed that the warmer the water, the bigger the difference between the maximum and minimum temperature recorded in one month and in one day. This can be seen by comparing the chart with records of a "cold week" and that of a "warm week" (Fig. II.7).



a)Temperature recorded between 14 and 21/03/82 - a 'cold week'.



b)Temperature recorded between 30/05/82 and 07/06/82 - a 'warm week'.

Fig.II.7 - Comparison between a chart of a 'cold week' (a) with another one of a 'warm week' (B).

Appendix 2 shows the water temperature at each depth in different months. Measurements were made only to 4m because this represented the mean depth of the lake during the year.

In the winter (mainly in January 1982) the surface of the lake was covered by ice and the temperature near the bottom was about 4°C. By the middle of February 1982 the lake was completely unfrozen, but low water temperatures (from 1°C in the surface to 4°C at the bottom) were constant until the middle of March (1982) when they started increasing very quickly. From the end of April 1982 to the end of May temperatures over 10°C were common and it was possible to observe a very slight difference between superficial and deeper water temperature. The highest temperatures were recorded from the end of May to the end of August 1982. At this time there was an increase in the temperature difference between the top and bottom of the lake. However, as the lake is quite shallow and very exposed, a typical thermal stratification was not well defined, although a drop of 2°C did occur from the surface to a depth of 4m. From September the temperature decreased gradually during the autumn, until the water showed a quite uniform temperature from the surface to the bottom during the winter.

The seasonal variation in water temperature at Cobbinshaw shows approximately the same pattern as other typical temperate lakes discussed in several works in freshwater ecology, e.g. Reid (1961), Mills (1971), Wetzel

(1975), and Maitland (1978). Such seasonal variations are closely related to the amount of total direct solar radiation received, the angle of the light, degree of disturbance of the water, transparency, depth, density and wind strength.

Water temperature has a very important effect on aquatic organisms, particularly as a result of the temperature density relationship. Water density reaches its maximum value at about 4°C. This phenomenon has enormous significance on thermal stratification of lakes, buoyancy of zooplanktonic organisms (Maitland, 1978).

Fish like most of the aquatic organisms are poikilothermic and depend on the effect of water temperature particularly in relation to growth, spawning, development and migration.

It is clear that Cobbinshaw perch and trout movements discussed before are related to change in water temperature. In the spring when the temperature reaches 10°C perch come in to shallow water for spawning. At the same time trout migrate to deeper and colder water. The opposite situation was observed in autumn.

Each fish species has a range of temperature at which they can survive (Mills, 1971). Thus, they are classified as stenothermal (e.g. trout) when adapted to a narrow amplitude of temperature and eurythermal (e.g. carp) when adapted to a considerable temperature range (Nikolsky, 1978). In the classification proposed by Varley (1967) the upper lethal limit for trout is below 28°C, the optimum temperature range for growth lies between 7°C and 17°C and for spawning is up to 10°C. The preferred temperature is 13.6°C.

For perch and pike he established an upper lethal limit between 28°C and 34°C, an optimum temperature for growth between 14°C and 23°C and> 10°C for spawning.

Such observations should be considered when stocking strategies are planned. In the case of Cobbinshaw, trout are put in the rearing cage and kept there from March to October. During this time they are restricted to a small area compared with that of the entire lake. Probably after release their movements are influenced by the condition under which they lived in the cage. In fact, Varley (1967) suggested that sensitivity of fish to water temperature depends on their previous thermal experience. Considering that the upper lethal limit for trout is below 28°C and Cobbinshaw water temperature may reach 25°C, it seems that fish should neither be put in the rearing cage nor introduced into the lake in the summer season. However, more supporting evidence is necessary before reaching a final conclusion on this.

II.7. Chemical analyses

II.7.1. Materials and Methods

Water sampling was carried out at monthly intervals in the area where most of the fish, bottom fauna and plankton were collected. Surface water was used for general analysis and samples from depths of 1, 2, 3 and 4m were used for estimating temperature and dissolved oxygen. Samples were taken by a *Friedinger water-bottle which allows water to be taken from a known depth and brought to the surface in an almost unchanged condition. A clean rubber hose was used to transfer water from the sampler to the sample bottle,which was filled up until the water overflowed: to ensure minimal contamination from the walls of the bottle it was rinsed before the actual sample was taken.

*Friedinger water-bottle consists of a brass cylinder with upper and a lower cover which remain open when the bottle is lowered. A winch fitted with a graduated cord is used to lower the bottle and a messenger is sent down the rope causing the release and closure of both the upper and lower covers.

To analyse the water in the field, a Hach DR-EL "Direct Reading" Portable Engineers Laboratory kit was used (Hach Chemical Company, Anes , Iowa, U.S.A.). The kit was calibrated by using deionized water and the following analyses were carried out:colour, turbidity, dissolved oxygen, carbon dioxide, pH, total alkalinity (bicarbonate), nitrate-nitrogen, nitrite- nitrogen, orthophosphate, total phosphate and silica.

All parameters were measured in parts per million (ppm=mg/l) with the exception of colour where the platinum-cobalt (Pt-Co) scale was used and turbidity which was in Jackson turbidity units (JTU). In order to obtain oxygen-saturation values a Rawson's nomogram (Welch, 1948) was used. As Cobbinshaw Reservoir is approximately 270m above sea level a correction was made according to the factor table associated to Rawson's nomogram (Welch, 1948).

II.7.2 **Results and discussion**

a)-Colour

The Platinun-Cobalt (Pt-Co) scale is that used by the United States Geological Survey. The method uses 1mg Pt/l as a standard unit, which ranges from zero in very clear waters to 500 units in very dark water.

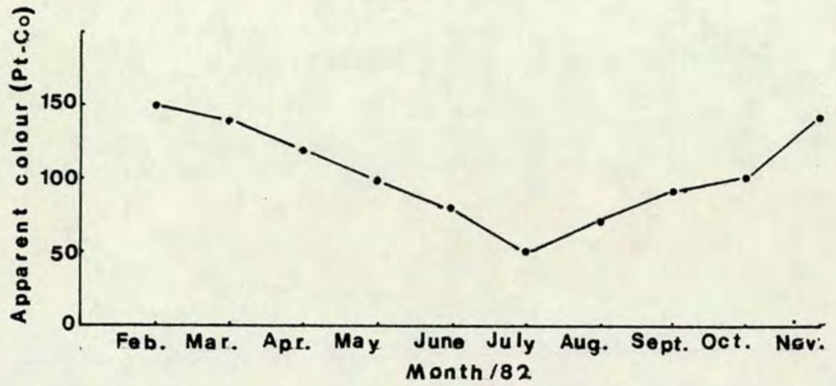


Fig. II.8 - Monthly variation of water apparent colour

Figure II.8 shows variation in the apparent water colour in different months.

Cobbinshaw Reservoir shows a range of 50 Pt-Co to 150Pt-Co, which means that the water is neither very dark nor colourless. In fact, when the lake is observed from a boat it shows a brownish colour, which is darker in the winter.

According to Maitland (1978), the colour of water which we see is due to the upward scatter of light and depends mainly on the amount of suspended materials. In some waters depth and bottom substratum are also important. Thus, water colour varies from dark in very pure and deep water, through blue or green in water with little suspended material, to brown in water with a large amount of suspended material.Presumably, the brownish colour of Cobbinshaw water is related to suspended colloidal peaty material, dissolved humic material and humic acids and organic material present in the bottom. It is possible that the presence of a large number of diatoms also contributes to the water colour (Welch, 1948).

Since fish can distinguish colour, the water colour and background are important factors affecting their distribution in a lake. Fish colouration varies during their development and is related to the colour of the background. This colour changes when they move from one habitat to another (Nikolsky, 1978). Trout are able to change colour in order to match their background due to the presence of dark pigment cells (chromatophores) in the skin (Mills, 1971). The pigments of these cells are under the control of the pituitary gland, the activity of which is influenced by light. On a dark background the pituitary secretes a hormone which causes dispersion of the black pigment, melanin and determines the darkening of the body colour (Frost & Brown, 1967). Nikolsky (1978) placed perch among fish with "vegetal colouration" which is the property of fish inhabiting weed reefs. Gaschott (1928) distinguished brightly coloured populations of perch with red pectoral, ventral and anal fins in rivers and lakes of North Germany from pale populations in sub-alpine and alpine lakes: this is probably related to water colour.

It was observed that in Cobbinshaw Reservoir trout colouration varies from silvery with black x-shaped spots to golden-yellow with red spots. Perch, on the other hand, showed a remarkable red fin before spawning. There is no evidence, however, if such colouration is related to changes in water colour during the year.

b)- Turbidity

The method uses the Jackson Turbidity Units (JTU) - Formazin Standard which ranges from 0 JTU in clear water to 500 JTU in very turbid water. JTU units represents the mg/l of suspended material in the water.

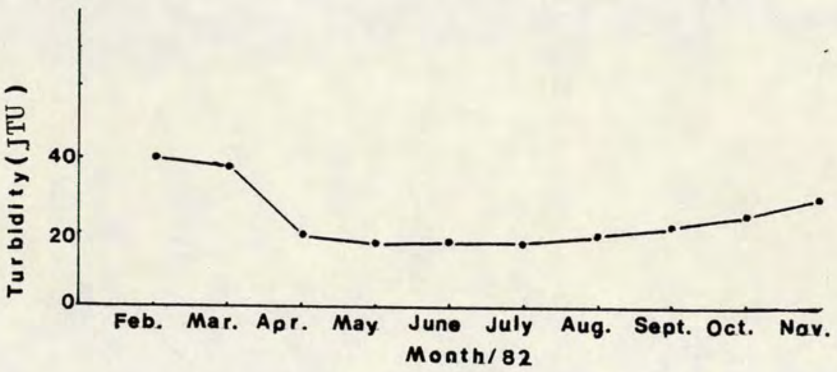


Fig. II.9 - Monthly variation of water turbidity.

Figure II.9 shows variation in water turbidity from February to November 1982. Cobbinshaw water varied from 16 JTU in July to 40 JTU in February. Such levels of turbidity indicate that there is relatively little suspended particulate matter in the water. The levels proposed by Alabaster & Lloyd (1982) are: clear ponds (<25mg/l), intermediate (25-100mg/l), and muddy (>100mg/l). They established the following criteria in relation to suspended solids: (1) less than 25mg/l is not harmful for fish; (2) from 25-80mg/l it is possible to maintain good fisheries;3) from 80-400mg/l it is not very suitable for good fisheries, but supports some fish and (4) more than 400mg/l suitable only for very poor fisheries. In general even very high turbidity may not kill fish and presumably turbidity is more harmful to water productivity than directly to fish.

c)- <u>Dissolved oxygen</u>

Fig.II.10 shows the concentration and Fig.II.11 the percentage of saturation of dissolved oxygen from February to November 1982. The reservoir showed a high concentration all the year round with the maximum value occurring in the spring and the minimum value in the summer.

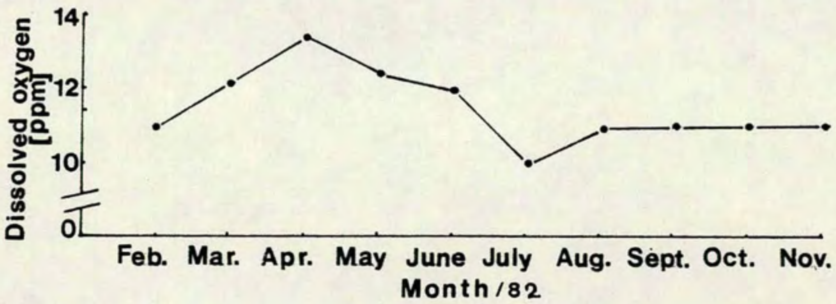


Fig.II.10 - Monthly variation of dissolved oxygen.

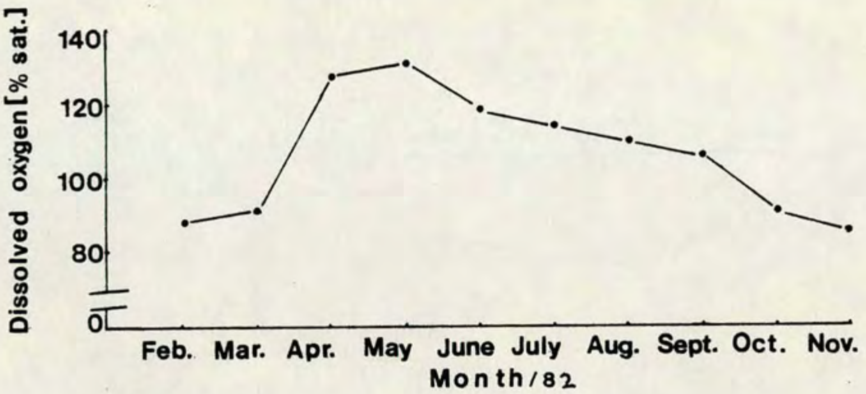


Fig.II.11 - Monthly variation of percentage saturation of dissolved oxygen.

Although the percentage saturation varies from undersaturation in the winter to supersaturation in the spring, the levels were always much higher than the minimum requirements for trout, perch and pike. Mills (1971) pointed out that the amount of oxygen normally required by fish, and the minimum concentration they can tolerate, differ drastically from one species to another. Salmonid waters, for example, should have a dissolved oxygen concentration of at least 80% saturation and the minimum lethal dose for trout is from 5.0 to 5.5mg/l. Wunder (1936) proposed that trout normally require from 10 to 16mg/l and begin to suffer if the concentration falls to 7mg/l. Perch need from 7 to 10mg/l while pike require only 5.7mg/l. Such values are approximated for medium temperatures for each species, as the actual requirements depend also on the concentration of other dissolved gases, particularly carbon dioxide and ammonia - the higher the concentration of these the more oxygen is required.

Records from the literature show a remarkable variation in the oxygen levels tolerated by perch. Meadows (1970) found perch in 1ppm concentration in the River Lee, England. Jones (1964) quoted values of 0.4–0.9ppm at 15.5°C; 1.1-1.3ppm at 16°C; and 2.25ppm at 20-26°C. Petrosky & Magnuson (1973) noticed an increase in gill-ventilation rate in perch when oxygen tension fell from 4 to 1ppm, and Petit (1973) found that amplitude of opercular movements also increased at levels below 6ppm. The last author observed bleaching, cessation of feeding and loss of equilibrium, among the effects of lethal oxygen starvation on perch.

The amount of dissolved oxygen in the water depends on several factors. Among them are contact between the water and the atmosphere, quality and quantity of organic substances present, circulation of water, water temperature, production by aquatic plants and consumption by other living organisms.

Concentration of dissolved oxygen in Cobbinshaw Reservoir varied from 10ppm in July to 13.5ppm in April. Such high concentrations are presumably related to the presence of a large number of algae and to the absence of polluted water running into the reservoir. Furthermore, due to exposure of the lake and frequent wind there is constant water circulation, with the exception of some days in the summer.

Lower values of dissolved oxygen recorded in the summer are related to higher temperature which reduces the oxygen concentration. On the other hand, a large number of dead zooplankton organisms and blue-green algae (scums) were noted in this season. Decomposition of these organisms, mainly by oxidation of organic matter, increases oxygen consumption and, consequently, decreases dissolved oxygen. Furthermore, increased metabolism of heterotrophic organisms in the summer also contributes to the increased oxygen consumption.

The occurrence of higher oxygen levels in the spring is related to natural circulation and mixing in that period and to the increase in the number of Algae.

Appendix 2 shows variation of dissolved oxygen at different depths from February to December 1982. Dissolved oxygen stratification was not observed in Cobbinshaw Reservoir, presumably due do the presence of quite shallow water. Hence there are no stagnation areas with declines of dissolved oxygen to levels below the necessary minimum for the fish species studied even in the deepest area. In spite of that, it may be possible that death of trout recorded in Cobbinshaw rearing cages in the summmer was related to a rise in temperature and the consequent decrease of oxygen concentration in the restricted cage environment.

d)- Carbon dioxide, alkalinity and pH

Alkalinity, pH and Carbon dioxide are discussed together because of their close relationship. Fig.II.12 (a,b,c) shows their variation from February to November 1982. These values were obtained about midday and readings taken at night could have been different since water temperature, photosynthesis and respiration influence the level strongly. Alabaster & Lloyd (1982) pointed out that high temperature and strong sunlight can raise the pH value to a high level for a short period of the day in lakes with high plant density.

As show in Fig.II.12, alkalinity varied from 30ppm to 50ppm, carbon dioxide from 15ppm to 24ppm and pH from 7.2 to 8.5. Such levels give Cobbinshaw Reservoir alkaline water. The variation showed a seasonal trend. pH and alkalinity decreased in the spring, increased in the summer and decreased again in the autumn, while carbon dioxide showed an inverse relationship.

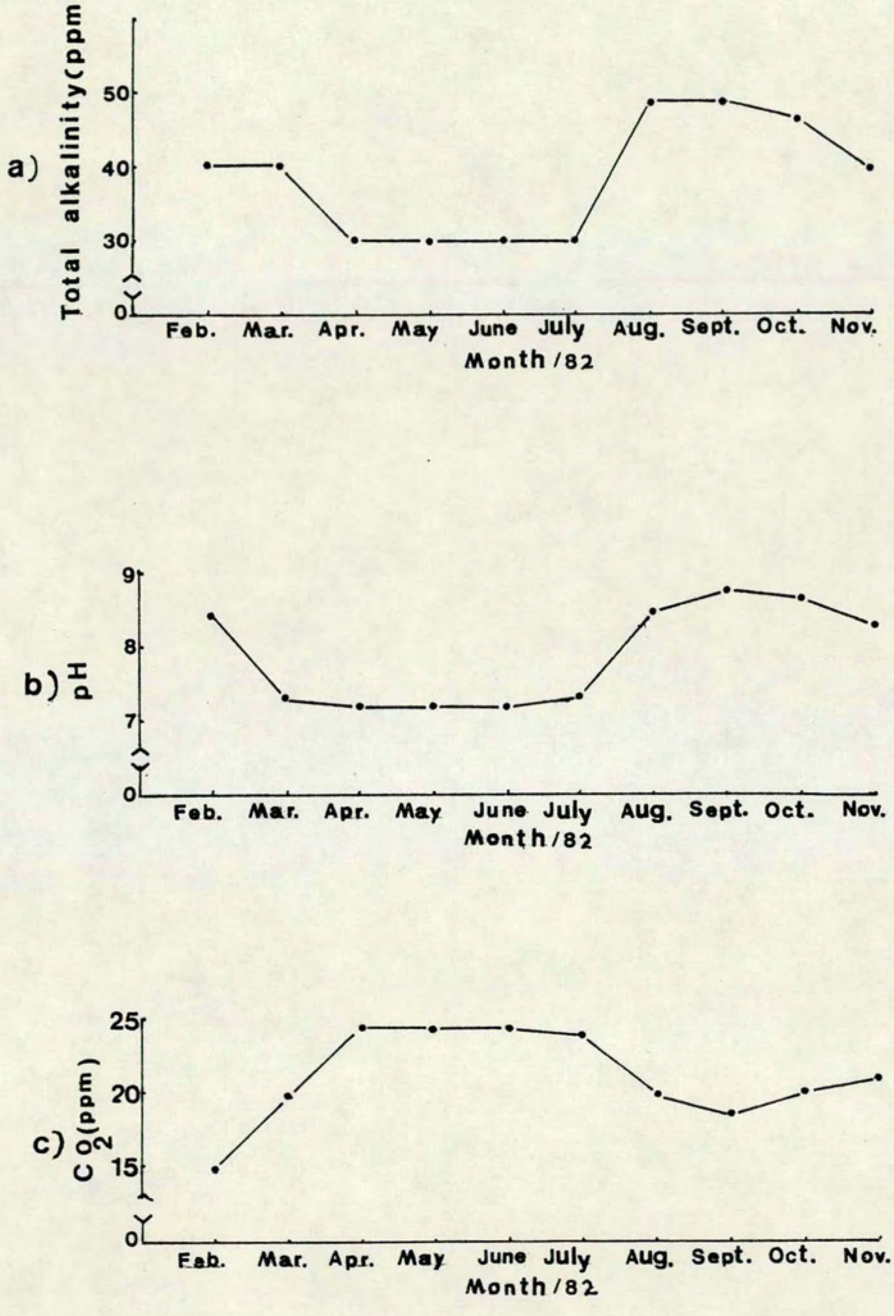


Fig.II.12 - Monthly variation of alkalinity (a), pH (b), and carbon dioxide (c).

During the winter when ice covers the water, oxidation of organic material brings about an increase in the carbon dioxide concentration, which contributes to increases in carbonic acid, bicarbonate ions (HCO_3^-) and H^+ and decrease in pH. In the summer photosynthesis and respiration are very important factors affecting CO_2 levels because of the presence of large numbers of algae and macrophytes and increasing metabolic activity. Respiration of living organisms, including those involved in the decomposition of organic material, contribute to increasing the amount of carbon dioxide, while photosynthesis of green plants contributes to its reduction. According to Ruttner (1975) in temperate zones, in the summer, the amount of carbon dioxide removed is more than that returned. Thus, the daily balance of asssimilation remains positive and leads to a gradual summation of effect, decreasing the amount of carbon dioxide and increasing pH.

Although photosynthesis and respiration are the major factors affecting carbon dioxide, alkalinity and pH levels, buffering which is influenced by water temperature and salt concentration, also plays an important role in modifying seasonal variations. Because of equilibria established by buffers the water tends to resist change in pH. This phenomenon is explained by Wetzel (1975) as follows: the most important sources of carbon dioxide in water are air, rain and the respiration of the living organisms. It reacts with water according to the reactions:

$$CO_2 + H_2O \dashrightarrow H_2CO_3 \tag{1}$$

$$H_2CO_3 \dashrightarrow H^+ + HCO^-_3 \tag{2}$$

$$HCO^-_3 \dashrightarrow H^+ + CO^=_3 \tag{3}$$

As these reactions are related to pH, there are three forms of carbon dioxide in water at different pH levels, i.e. free CO_2 in water of pH 5 and below, HCO^-_3 between pH 7 and 9 $CO^=_3$ above pH 9.5.

The presence of the bicarbonate ion (HCO^-_3) is important for aquatic organisms because by combination with calcium it produces calcium bicarbonate. By dissociation HCO^-_3 produces H^+ and $CO^=_3$ and by hydrolysis it produces H_2CO_3 and OH^-. Alkaline waters are produced by the OH^- ion and the number of H^+ ions is conventionally used to define pH.

The carbon dioxide-bicarbonate-carbonate complex has the property of maintaining a near neutral condition in mineralized waters by buffering the system.

Values of alkalinity recorded in Cobbinshaw Reservoir (30-50ppm) are considered low when compared with the 150ppm proposed by Frost & Brown (1967) as the threshold of optimal trout growth. However, alkalinity is only one of the factors affecting fish growth, and presumably is not the most important in Cobbinshaw Reservoir.

Values of pH recorded in Cobbinshaw water (7.5-8.5) showed that there has been an increase in pH since 1975, when Boyd (1975) recorded values of 6.5. Such observations suggest that Cobbinshaw water is not being affected by acid precipitation which tends to increase water acidity. However, it is necessary to mention that Boyd's (1975) results were obtained from only one sample and he did not mention what time the sample was collected.

Indeed, it is difficult to account for why Cobbinshaw Reservoir has basic water in spite of the presence of bog areas and surrounding moorland. Presumably, this is a consequence of the summation of buffering and presence of intrusion of limestone to the west of the lake, and shales and carboniferous sandstones in areas adjacent to the reservoir.

Regarding the effect of extreme pH on fish, Alabaster & Lloyd (1982), admitted that the existing data are neither as comprehensive, nor as accurate, as would be ideally required for the formulation of definite criteria for each fish species. However, they suggested that the pH range which is not directly lethal to fish is 5-9 and that there is some evidence that the young fish are more sensitive than the adults and that resistance to extreme pH values increases with age.

Mibbrink & Johanson (1975), showed that viability of perch eggs in natural lake waters with a range of acidities was reduced below 4.7. For pike they found that the figure was 5.0. Dahl (1927) observed that 80% of trout in the yolk-sac stage died within 20 days at pH values of 4.7-5.4 in water acidified with peat. Alabaster & Lloyd (1982) suggested that according to results of Lloyd & Jordan (1964) brown trout are more resistant to low pH than rainbow trout and probably can be acclimatized to acid environments.

Menzies (1927) and Campbell (1961) found natural populations of trout at pH values as low as 4.5. Alabaster & Lloyd (1982) showed that perch and eel (Anguilla anguilla) appear to be the most pH resistant species occurring in lakes.

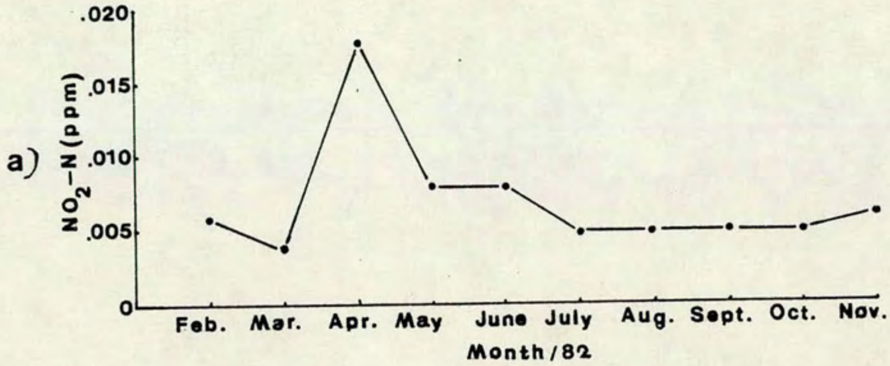
Regarding the effect of very high pH on fish life, Eicher (1946) found blind trout with frayed dorsal and caudal fins dying at pH value of 10.2. Bandt (1936) found that the lethal pH for trout and perch in alkaline water was 9.2 and for pike 10.7.

In relation to the growth of fish, Southern (1932) showed that trout grew more rapidly in alkaline than acid waters. Pentelow (1944) suggested that food supply is more important for growth than the degree of alkalinity. However, Frost (1939) concluded that some factors other than food supply were responsible for the lower growth of trout in acid water compared with alkaline. Campbell (1961) found no correlation between pH values and growth rate of trout in nine lakes with pH values ranging from 4.9 to 8.4. In acid and alkaline water under conditions where no spawning occurred he found that the growth of artificially stocked trout at low density was the same.

pH and alkalinity values recorded in Cobbinshaw Reservoir showed that the water is suitable for trout, perch and pike. According to the classification of the effects of pH values on fish proposed by Alabaster & Lloyd (1982), Cobbinshaw Reservoir is included in the range from 6.5-9.0, i.e, 'harmless to fish, although the toxicity of other poisons may be affected by changes within this range.' However, they emphasised that these effects need more support from future experience.

e)- Nitrate - nitrogen and nitrite - nitrogen

Values of nitrate-nitrogen (NO_3-N) and nitrite-nitrogen (NO_2-N) were very low as shown in Fig.II.13(a,b). Nitrate-N varied from 0.35ppm in the winter to 0.05ppm in the summer. Nitrite-N, on the other hand, varied from 0.004ppm in late winter to 0.018ppm in early spring. Such low concentrations are a property of unpolluted waters with no sewage input. Usually, the flow of sewage into the water is the most common source of ammonia, which can be converted in nitrate sometimes reaching 12ppm in extremely polluted water. In unpolluted water the main source of Nitrogen is the atmosphere, surface run-off containing terrestrial compounds of nitrogen (nitrate, ammonia), inflow of ground water, and fixation by bacteria and algae.



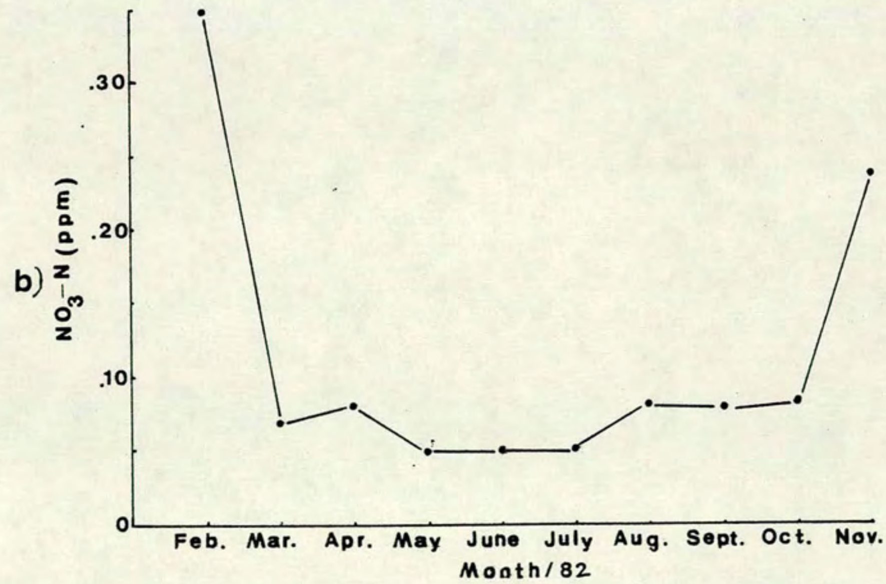


Fig.II.13 - Monthly variation of Nitrite-nitrogen (a) and nitrate-nitrogen (b).

There is little information on the influence of nitrate and nitrite on fish ecology, but it is known that higher concentrations of nitrogen compounds (particularly in the form of amnonia) can be harmful to fish and contribute to blooms of blue-green algae during the spring.

Presence of nitrogen compounds is important for water productivity as they are a basic component of proteins.

Variation of nitrate and nitrite in Cobbinshaw Reservoir is presumably related to water temperature and the presence of bacteria, algae and green plants. According to Reid (1961) the higher the temperature the lower is the solubility of molecular nitrogen.

Green plants also require nitrate for their metabolism and this presumably explains the lower nitrate concentration during the growing season (summer). Utilization of nitrate by phytoplankton in summer can drastically reduce its concentration in the upper strata of lakes while at the same time higher values can be observed in the hypolimnion, particularly in meromitic and eutrophic lakes (Ruttner, 1975).

In late autumn nitrate and nitrite concentrations were low as a consequence of biological activities during the summer. Then, they increased to a peak in late winter (nitrate) and early spring (nitrite). Such variations are also related to the number of diatoms which are capable of reducing nitrate to nitrite (Reid, 1961).

f)- <u>Silica</u>

Figure II.14 shows the variation in silica concentration. Higher values (3.4ppm) occurred in the winter and lower values (1.5ppm) in spring and summer.

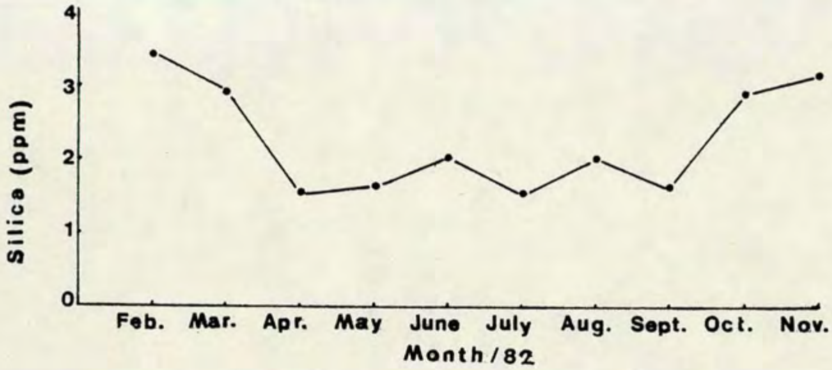


Fig. II.14 - Monthly variation of silica.

Soils and rocks are the most important source of silica in aquatic environments and stretches of water on sedimentary rocks are the richest in silica compounds (Reid,1961). However, within a given region, the concentration may be quite variable. In Florida, for instance, in an area of sedimentary rocks, Reid (1961) found concentrations ranging from less than 1mg/l to over 30mg/l. The concentration in Cobbinshaw water ranges from 1.5 to 3.4mg/l which is low compared to some of the Florida values but is considerably higher than bog water which generally has less than 1mg/l (Ruttner,1975).

Silica is not an important component of the living protoplasm, however, it occurs in the skeletal structures of some organisms, such as frustules of diatoms, spicules of some sponges and so on. There is no record of any direct effect on fish ecology.

Many works suggested that the concentration of silica in the aquatic environment is important in determining the presence of diatoms (Einsele & Vetter, 1938; Reid, 1961; Ruttner, 1975).Populations of Asterionella, Melosira and Tabellaria for example, are limited by concentrations of from 0.5 to 0.8mg SiO_2/l (Reid, 1961). Such observations suggest that the drop in silica concentration in Cobbinshaw Reservoir in early spring is related to its incorporation in the frustules of the increasing population of diatoms. The low values persist through the summer correlated with high diatom populations and also perhaps to incorporation of silica by Equisetum (Wetzel, 1975), which grows very quickly in that season. In addition to the relationship between silica concentration and number of diatoms other factors not investigated in this work also affect the concentration of silica. Among such factors Wetzel (1975) pointed out surface adsorption of silica acid, formation of silicate complexes with iron and aluminium hydroxides, presence of humic compounds, dilution by run-off water, currents, movements produced by benthic organisms, gas-bubles escaping from sediments, loss of silica in dead algae, consumption of diatoms by zooplankton, allochthonous input and so on.

g)- <u>Orthophosphate and total phosphate</u>

Fig.II.15 shows the concentration of orthophosphate and total phosphate. Ortophosphate varied from 0.01ppm to 0.04ppm and total phosphate from 0.01ppm to 0.009ppm. Normally, in unpolluted water orthophosphate and total phosphate concentrations may range from less than 1ppm to more 200ppm, which means that the concentration of these compounds in Cobbinshaw Reservoir is quite low. Orthophosphate and total phosphate represent only a very small portion of phosphorus available in the lake, as according to Wetzel (1975) more than 90% of the phosphorus in lake systems is represented by organic phosphates and cellular constituents in living organisms or in dead particulate matter. Such organic compounds were not estimated.

Phosphorus has no direct effect on fish ecology, but due to its role in biological processes it is closely related to water productivity: according to Vollenweider (1968) there is generally correlation between total phosphorus present and lake productivity.

As shown in Fig.II.15 concentrations of orthophosphate and total phosphate show seasonal variation, with lower values recorded in the summer presumably due at least partially to increased incorporation in living organisms.

Other factors are also responsible for seasonal variation of phosphorus. Among them are chemical composition of the surrounding land, land use, concentration of iron and dissolved oxygen, pH, annual cycles of mixing, etc. (Wetzel, 1975).

In spite of the low concentration found in Cobbinshaw Reservoir it is important to consider that many compounds (e.g. silica, phosphorus and nitrogen) may be recorded in some water only as "trace elements". However, even in small concentrations they play an important role as a resource for aquatic organisms directly involved with water productivity.

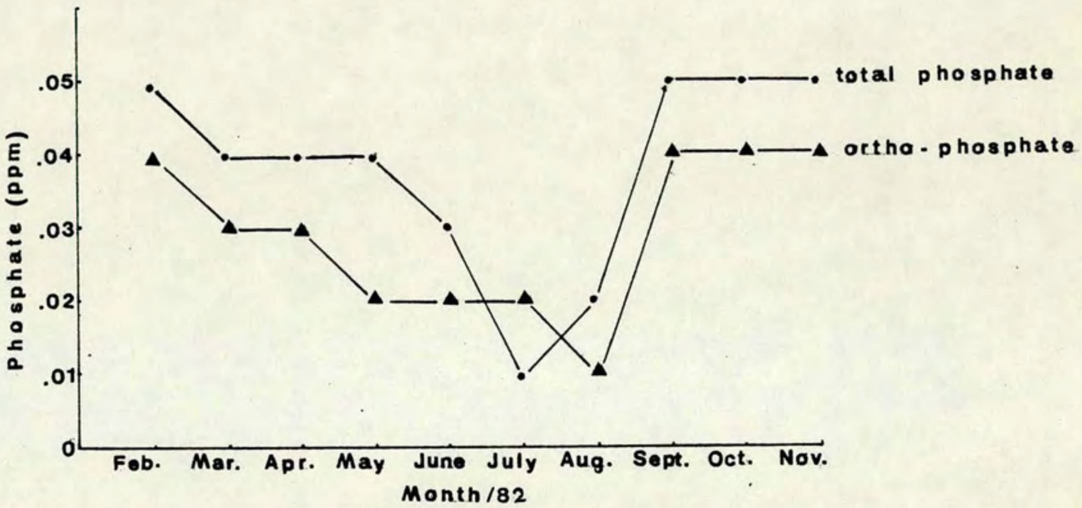


Fig. II.15 - Monthly variation of total phosphate and orthophosphate.

III. STUDIES ON PLANKTON AND BOTTOM FAUNA

III.1 Introduction

The aim of the present chapter is to describe the seasonal abundance, size and distribution of invertebrates in order to relate them to the feeding habits and interrelationships between perch and trout.

The literature contains many references related to the study of invertebrate fauna of lakes. However, some authors (e.g. Wetzel, 1975) consider that the information available is insufficient to understand the complete structure of the invertebrate communities in aquatic environments. This is mainly due to the heterogeneous distribution of organisms within aquatic systems.

Problems are also very evident in studies attempting to establish the relationship between available food and the feeding-patterns of fish, and practical considerations, such as time and the factors mentioned in the previous paragraph, have usually forced investigators to concentrate on either the feeding-patterns or the food availability in the community.

Investigations are usually confined to making descriptive analyses of the type of organisms and their distribution, while aspects of population dynamics and trophic interrelationships are poorly understood.

Among the problems faced by researchers in this area are those of quantitative sampling, separation of organisms from sediments, evaluation of cohorts among populations showing continuous reproduction, variations produced by emigration and immigration in populations of certain groups and difficulties in identification of certain organisms (Wetzel, 1975).

Ball (1948) studied the relationship between available fish-food, feeding habits of fish and fish-production in a Michigan lake. He concluded that (1) there is a relationship between the production of aquatic invertebrates fed upon by fish and the total production of fish; (2) there is a critical volume of aquatic invertebrates necessary to support growing fish-populations; (3) the relative productive capacity of a lake depends on the seasonal variation in number and volume of invertebrates;(4) in the lake studied the most productive area was the plant zone, which comprised about 35% of the total area of the lake and only 6% of its volume.

Guma'a (1978a) studied the food of perch and the change in mean concentration of zooplankton in the 0-5m stratum of Windermere (England) in order to provide a list of the food-organisms taken by young perch in the first summer of their life. He concluded that there was positive selectivity for some organisms, for example Bosmina obtusirostris (S.) and Copepoda (cyclopoid and calanoid) and negative selectivity for Daphnia hyalina var galeata (S.), Leptodora kindti (F.) and Bythotrephes longimanus (L.). He also pointed out that food selection in perch is limited by the availability of prey, its size, colour, mode of swimming and size of the fish's gape.

Mittelbach (1981) pointed out that the relative size of predator and prey is of major importance in determining the diet, energy intake and rate of growth by fish and that the time taken to find and handle the prey item is directly related to prey-size. He claimed that his study represents a first attempt to quantify the total size distribution of invertebrate prey found in natural lakes and that the work of Werner et al. (1977) represents the only other study which has attempted to determine the size distribution of prey in a freshwater system. In both studies it was found that distribution of prey sizes in each habit is lognormal.

It is well-known that the mode of foraging of fish depends on the size of food-organisms and this is related to the physical structure of each habitat. Therefore the present work concentrates on the size distribution and abundance of bottom fauna in different substrata and of planktonic organisms. These characteristics are very important in the study of competitive interactions (Wilson, 1975; Werner et al., 1977), habitat selection (Mittelbach, 1981), and 'optimal' body-size relations in predators (Schoener, 1969).

Recently, researchers have attempted to explain and predict the foraging behaviour of animals on the basis of an approach usually referred to as optimal theory. In this context feeding is treated as a devise whose performance may be maximized by natural selection, i.e., natural selection will elect those foraging patterns in a species that are most economical (Werner & Hall,1974). According to Schoener (1971) four aspects are important in the optimization of feeding: a) the optimal diet; b) the optimal foraging space ; c) the optimal foraging period and d) the optimal foraging-group size. Such an approach has been applied to fish, particularly in the study of optimal foraging-group size (Werner & Hall,1974) and optimal foraging space (Ware,1975).

Previous studies of invertebrates in Cobbinshaw Reservoir

There is no record of a regular monitoring of invertebrates in Cobbinshaw Reservoir and only a few works mention aspects of these organisms. Armistead (1915) referred to the presence of shrimps, bloodworms and water -fleas and reported absence of molluscs, probably due to the lack of weeds in the lake at that time. Malloch (1949) mentioned the abundance of bottom-feeding and little evidence of insect larvae. Boyd (1975) found the following organisms in samples taken from the littoral area in December, 1974: crustaceans (*Gammarus pulex* and *Asellus aquaticus*), molluscs (*Limnea pereger* and *Anodonta cygnaea*) insects (Tipulidae, *Chironomus*, *Limnephilus* and *Corixa*). On the muddy bottom he found a very few *Chironomus* and *Tubifex tubifex*. Among planktonic organisms *Daphnia hyalina*, *Chydorus ovalis*, *Diaptomus vulgaris* and *Cyclops viridis* were identified.

III.2. Materials and Methods

III.2.1 Plankton

There are various methods for collection of planktonic organisms most of which are discussed by Welch (1948) and Hellawell (1978). In this study, as a result of a sampling trial, a 30cm diameter plankton net with 68 meshes per cm and an aperture size of 0.0076cm was used.

The major advantage of using a net for plankton sampling is that it can filter a large amount of water in a short period of time thus giving a reasonable record of the species present.

Welch (1948) suggested making a set of physicochemical records before setting up a plankton sampling programme in order to obtain an indication of the most representative sites for study. As discussed previously, due to the predominance of shallow water, Cobbinshaw Reservoir shows neither thermal nor chemical stratification. Therefore, samples were taken by vertical hauling of the plankton net through the whole depth of the lake. This method has the advantage of collecting samples from the entire column of water.

Tonolli (1971) suggested that the volume of filtered water can be calculated according to the equation $V=\pi r^2 d$ where v=volume of filtered water; r = radius of the mouth of the net and d = the length of the course of the net through the water. Considering that the mean depth in the sampling area was 2.5m, the volume of filtered water was $V=3.1416 \times (15cm)^2 \times 250cm = 176715cm^3 = 176,7$ litres. Volumes calculated by this method are not very accurate since due to its resistance the net filters better at the beginning of the collection than at the end. In this work this error was minimized as the net was pulled at a very short distance. Welch (1948) proposed that 76 litres of filtered water usually provided a satisfactory population representation even during the seasonal low of plankton.

Samples were taken in areas where fish were collected (Appendix 4). Concentrates were preserved in 4% formalin and examined on the stage of a microscope by using a counting cell similar to the Sedgwick-Rafter discussed by Welch, 1948.

The counting cell was constructed by sealing an acrylic retangle, 50x20x1mm to an ordinary 1x76mm glass microscope slide. It had a capacity of 1ml.

Examination of organisms in each concentrate was made as follows: First, the counting cell was placed on a level surface and a glass coverslip was laid diagonally across the middle of the counting cell leaving an uncovered area at each end. Then, the concentrate bottle was inverted slowly and gently 10 times to mix the contents. Next a sub-sample of the concentrate was taken with a pipette which had the tapered tip cut off in order to give a truly representative sample. The counting cell was filled by introducing the pipette into one of the open ends and the unused part of the pipette sample was then returned to the concentrate bottle. Then, the counting cell was completely covered with the glass coverslip and agitated until the whole cell was filled and no bubbles were present.

After transfering the counting cell to the microscope, all the organisms in the sub-sample of 1ml were counted as follows: each separate organism, filament, colony and egg-mass were counted as one plankter. All debris, cast-skins and fragments of plankters were ignored. Larger organisms (Copepoda, Cladocera, etc.) were counted using a x4.8 objective lens and smaller (Algae, Rotifera, etc.) a x 10 objective lens. Planktonic organisms were measured using an eyepiece micrometer.

The counting procedure was repeated 10 times for each concentrate bottle and the mean number of organisms per ml was calculated. These data were used to calculate the number of organisms per litre of concentrate and from this the number in the water of the sampling area.

III.2.2 **Bottom fauna**

Trial samplings were made in different substrata before establishing a sampling strategy, which included collection in the areas showed in Appendix 4.

Collection of samples in areas over 1m deep was made with an Ekman grab (Hellawell, 1978), using the technique described in chapter two.

After passing the sample through a vertical nest of sieves, organisms were separated and preserved in 4% formalin. Later they were identified and counted using a microscope.

In the littoral area (less than 1m) samples were taken using a $30cm^2$ net with 24 meshes/cm. Each sampling station was studied using square metre plots in which collections were made by disturbing the bottom by kicking with the feet. This technique was discussed by Hellawell (1978) who concluded that in spite of some limitations it provides very consistent and suitable data for assessing approximate average population densities.

The measurements of the organisms took place using a ruler for larger organisms and the eyepiece micrometer (used in plankton studies) for smaller ones. All the organisms in each sample were counted.

III.2.3 Identification of organisms

Organisms were identified using keys, or with the help of specialists. The keys used were Ward & Whipple,1959, Needhan & Needhan,1962 Maitland,1978 and Macan,1981 (general identification). Scourfield & Harding,1966 (Cladocera), Harding & Smith,1974 (Copepods), Chinery,1982 (insects) Chancelor,1962 (plants and algae) and others scientific publications of the Freshwater Biological Association.

III.3 Results and discussion

III.3.1. Phytoplankton

The following algae were found in the phytoplankton population of Cobbinshaw Reservoir, following the classification of Ward & Whipple (1963). Division Chlorophyta (green algae): Sphaerocystis sp, Pediastrum sp, Closterium sp, Staurastrum spp, Euastrum sp and Spondilosium sp. Division Cyanophyta (Myxophyceae or blue-green algae): Aphanizomenon sp, Coelosphaerium sp and Oscillatoria sp. Division

Baccilariophyceae (diatoms): Melosira sp, Navicula sp, Tabellaria sp and Asterionella sp. Division Pyrrophyta: Ceratium sp.

Table III.1 shows the monthly variation of the dominant phytoplanktonic species. The Chlorophyta was the division with the greatest number of species but only two of these, both belonging to the genus Staurastrum,(and neither were identified to species) were important in terms of numbers. The numbers of Staurastrum sp1 increased from February to June and then decreased again until the next growth period after the winter. Staurastrum sp2, on the other hand, first appeared in August when the number of Staurastrum sp1 was decreasing and had a very short presence (from August to September - Table III.1).

In the spring (from March to May) there was a bloom of Cyanophyta (Aphazimenon sp). These organisms reached a peak dominance in March and then the number dropped until they disappeared completely in June when they were replaced by a Coelosphaerium sp whose number peaked in August. It seems that blue-green algae are the dominant planktonic algae in the Reservoir all the year round (Table III.1) and concentrated masses of these algae ('scums') were recorded from May to October.

The seasonal variation in diatom numbers was very different from blue-green algae. The population of Asterionella, the most common diatom, increased from February to March, declined somewhat in the next three months and then climbed to a peak in October (Table III.1).

Although an Asterionella species was the most abundant species, Melosira, Navicula and Tabellaria were also frequent.

The Pyrrophyta were represented by a few short-lived organisms of the genus Ceratium (Table III.1). They were first recorded in July when they were at their maximum numbers but a residual population was recorded for the next two months.

Table III.1 - Monthly variation in the number per litre of dominant species of algae

SPECIES \ MONTH 1982	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.
Staurastrum sp1	564	4825	5650	6402	7373	6435	5252	3991	1068	598
Staurastrum sp2	0	0	0	0	0	0	4892	158014	250	0
Asterionella sp	6529	10324	12561	9560	8942	6130	10348	54064	232382	197904
Coelosphaerium sp	0	0	0	0	11534	164630	428752	207901	3815	1388
Aphanizomenon sp	1251	835536	650151	251158	0	0	0	0	15030	6162
Ceratium sp	0	0	0	0	0	5711	320	47	0	0

The phytoplankton of Cobbinshaw Reservoir consists of large populations belonging to few species, amongst which blue-green algae are particularly well-represented. This classifies the Reservoir as eutrophic according to Hutchinson (1967) and Wetzel (1975) in contrast to oligotrophic lakes which show many species amongst which green-algae (mainly Staurodesmus and Staurastrum) are dominant. However, abundance of Staurastrum possibly indicates that Cobbinshaw should be considered mesotrophic rather than eutrophic in terms of algal association: the literature is far from agreed on such classifications and really a better knowledge of algal ecology is needed before a definite conclusion can be reached.

In spite of having only a single sampling area and the relative infrequency of sampling, it was possible to observe that the phytoplankton shows marked seasonal trends. Variation in the diversity and number of organisms seemed to be related to seasonal changes in water temperature and was more evident from spring to summer. Bailey-Watts & Duncan (1981) suggested that associated conditions - increases in temperature, changes in light regime and decreasing water level - make the water more favourable for algae during the summer.

The chemical characteristics of the Reservoir are other important factors influencing algal biomass. Bailey-Watts & Duncan (1981) observed a close relation between increase in algal biomass and pH, alkalinity, total cations, inorganic nitrogen and phosphorus.

Due to the presence of a siliceous cell-wall in diatoms, many works have tried to establish a relationship in this group between silica utilization and its concentration in the water. However, this interaction is not completely understood, for example, Bailey-Watts (1976) found no simple relationships but Lund (1949, 1950, 1955), Jorgensen (1957) and Hutchinson (1967) all observed a strong positive relationship. In Cobbinshaw Reservoir an increase in the numbers of diatoms from February to April coincided with the decrease in silica concentration. Conversely, in winter when higher concentrations of silica were recorded the number of diatoms was very low. However, this direct relation did not hold from May to November.

Naturally, factors other than physico-chemical characteristics also influence phytoplankton variations. Among then are grazing by zooplankton, sinking and predation. In Cobbinshaw Reservoir, for example, young perch (under 1cm) collected in early June were consuming different kinds of algae and diatoms. This observation was also recorded by Guma'a (1978a) in Windermere.

Considering that the phytoplankton community represents a number of different populations co-existing in the same habitat, and as each species has a niche based on physiological requirements, Wetzel (1975) suggested that competition could be another factor affecting seasonal variation of the algal biomass.

The seasonal variation observed in Cobbinshaw Reservoir follows the seasonal patterns and periodicity described in the literature (for example Wetzel, 1975) for temperate lakes with a tendency to eutrophy. In the winter a low number of organisms is recorded. This number increases greatly to a spring maximum when blue-green algae (mainly *Aphanizomenon*) and diatoms (for example *Asterionella*) are among the dominant organisms. Then, there is a decrease in early summer followed by a summer explosion of blue-green algae and diatoms that persists into the autumn.

Although it is difficult to make generalizations about algae periodicity due to the great variability observed in numbers and biomass of phytoplankton from lake to lake, Wetzel (1975) suggested two points which are reasonably consistent: a) seasonal changes are very repetitive from year to year on a short-term basis. b) seasonal amplitude of changes in phytoplankton number and biomass is usually very great, on the order of a thousandfold.

III.3.2 **Zooplankton**

Table III.2 shows the most important zooplanktonic organisms recorded during this study; these consisted of rotifers (presumably more than one species), Crustacea Cladocera (*Daphnia hyalina*, S., *Ceriodaphnia reticulata* J, *Bosmina coregoni* S. and *Holopedium gibberum* Z.). Copepoda (*Cyclops strenuus abyssorum* S. and nauplius larvae). However, others were recorded as well. They were mainly Cladocera (*Chydorus sphaericus*, M) Copepoda (one unindentified species of Calanoid), and Nematoda.These organisms were not considered in this study because of the casual nature of their occurrence.

Analyses showed that the dominant zooplanktonic organisms of Cobbinshaw Reservoir had a similar seasonal variation. In general, numbers were low in winter and increased after May to reach a peak in the summer, particularly in June (*Cyclops strenuus*,*Daphnia hyalina*, Bosmina coregoni, Holopedium gibberum) and July (Ceriodaphnia reticulata). Thereafter numbers decreased.

Table III.2 - Monthly variation in the number per litre and mean length of dominant zooplanktonic organisms in 1982.

Organisms	Mean length	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.
D. hyalina	2.9	10	5	100	500	4018	1451	679	348	277	161
B. coregoni	0.7	201	10	50	210	2009	1613	226	1740	2357	2904
C. reticulata	1.1	0	0	25	100	201	968	453	232	139	81
H. gibberum	1.0	0	164	328	577	804	161	0	0	0	0
C. strenuus	1.3	603	820	1005	1500	3415	1774	2490	1856	693	1129
Nauplius larvae	0.6	804	0	0	100	1205	1290	4527	232	0	1613
Rotifers	0.6	1808	1969	3000	15000	15871	12580	25127	39909	4437	15322

Such variation is presumably related to reproductive cycles which are strongly affected by changes in light and water temperature and the drop in water level. Such seasonal cycles in zooplankton of temperate lakes have been discussed by Hutchinson (1967), Wetzel (1975), Maitland (1978), Maitland et al. (1981) and others.

Fig.III.1 shows the variation of total number of Rotifers (the most abundant zooplanktonic organisms) and Crustacea.

The numbers of rotifers was low in the winter and increased from April to 15871 individuals per m^3 in June. There was then a slight drop until July after which the number increased to reach a peak density of 39909 individuals per m^3 in September. The number fell again in

October after which a new burst of growth started (Fig.III.1). The overall pattern of variation is probably brought about by superimposition of different seasonal patterns characterizing the different species which make up the population.

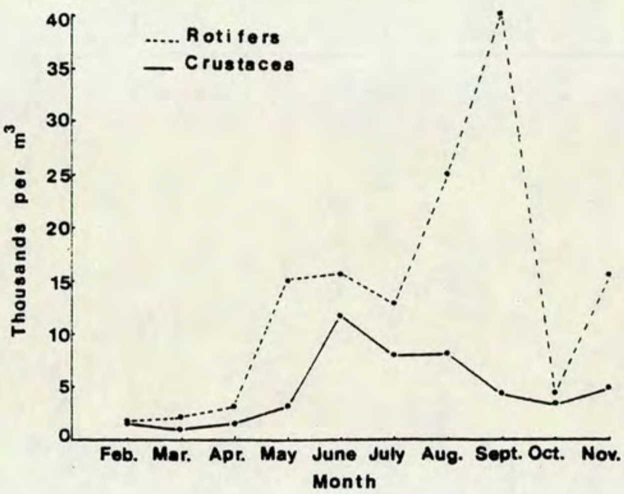


Fig.III.1 - Monthly variation in the total number of rotifers and Crustacea (including Nauplius larvae).

Levels of rotifer populations are mainly influenced by water temperature and food quality and quantity, which affect the rate of reproduction, development of eggs, feeding movement and longevity. Wetzel (1975) described two types of patterns of seasonal population change in rotifers. The first includes perennial species, which show maximal densities in early summer, and the second includes two distinctly seasonal type: (a) cold stenotherms with greatest populations in winter and early spring and (b) species that show peak numbers in summer, often with two or more maxima, especially occurring in late summer in conjunction with the development of certain blue-green algal populations.

Feeding behaviour of rotifers varies from one species to another, which permits their separation into a number of food-niches on grounds of the size-classes of food. Wetzel (1975) suggested that such fairly discrete niches are probably adequate to permit co-existence without the type of severe competitive interaction which leads to the elimination of populations. However, interaction among species is poorly undestood.

Cladocera and Copepoda also showed a seasonal trend with a dominance of organisms in summer.

Cyclops strenuus, the second most frequent zooplanktonic organisms if all rotifer species are lumped as a single population, was found throughout the year (Fig.III.2). Numbers were very low in the winter but started to increase in February. From May there was a very quick rise to a maximum of 3415 individuals per m^3 in June. Following this numbers fell in July, increased in August, dropped again in September and October and increased once more in November (Fig.III.2).

Higher temperatures and low water-levels observed in the summer are important parameters affecting the rate of egg-production and acceleration of development time (Wetzel, 1975). Furthermore improved food-availability in summer directly influences clutch-size. Copepoda Cyclopoida are in general carnivorous, and cannibalism is very common.

Seasonal variation among Copepoda are related to their early development which includes egg-stages, nauplius larvae and five copepodites. The duration of each stage is highly variable among species.

According to Wetzel (1975) Copepoda enter various periods of diapause, either at the egg-stage or in copepodite stages. Thus, the annual cycle is interrupted by diapauses that persist from one to several months.

Fig.III.2 also shows the variation in number of nauplius larvae. They were present in low numbers in the winter but disappeared in March. After this the population started to rise from April and reached a peak of 4527 individuals per m^3 in August. Following this, numbers decreased rapidly until they disappeared in October. However, in November they made a re-appearance in quite large numbers. It seems that Cyclops strenuus breeds twice a year as the number of Nauplius larvae had two peaks; one in late summer and another in late autumn, which suggests a bimodal population. Harding & Smith (1974), described Cyclops strenuus abyssorum as a monocyclic species, breeding in late summer and autumn. Maitland et al. (1981) found that the populations of C.strenuus in five Scottish lakes were small during the winter increasing in May to reach peak densities either in June (Loch Lomond and Loch Awe), July (Loch Ness and Loch Morar), or August (Loch Shiel). In Cobbinshaw Reservoir the density of Cyclops strenuus abyssorum was higher than in these five very large Scottish lakes. The pattern of variation in Cobbinshaw was most similar to Loch Awe with the exception of the increase in November (Fig.III.2), which did not occur in the latter. However, it must be borne in mind that Maitland et al.'s data were for large oligotrophic lakes whereas Cobbinshaw is fairly eutrophic and, in comparison, very small.

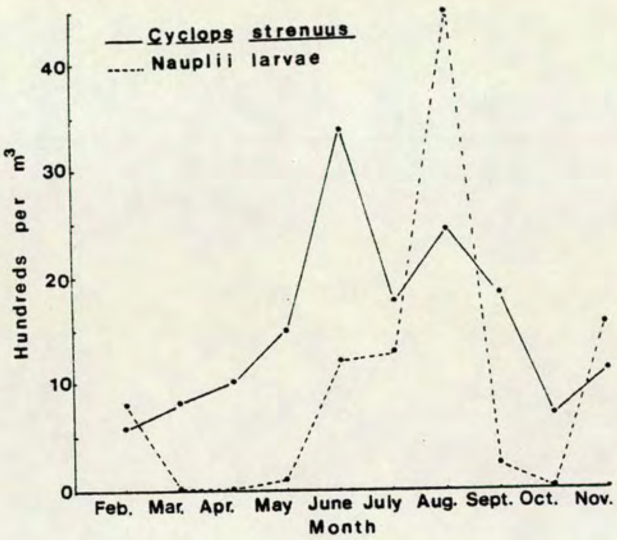


Fig.III.2 - Monthly variation in the number of Cyclops strenuus abyssorum and Nauplius larvae .

Cladoceran crustaceans were the third most numerous organisms. The following species occurred in declining order of frequency: Daphnia hyalina, Bosmina coregoni, Ceriodaphnia reticulata and Holopedium gibberum. The total Cladocera in the lake show peak numbers in June and July and low numbers during the winter; the graphs given in Fig.III.3 show the monthly population variation for each species and demonstrated that Bosmina coregoni has two peaks (the highest in November) whilst the other three species show only a single summer peak.

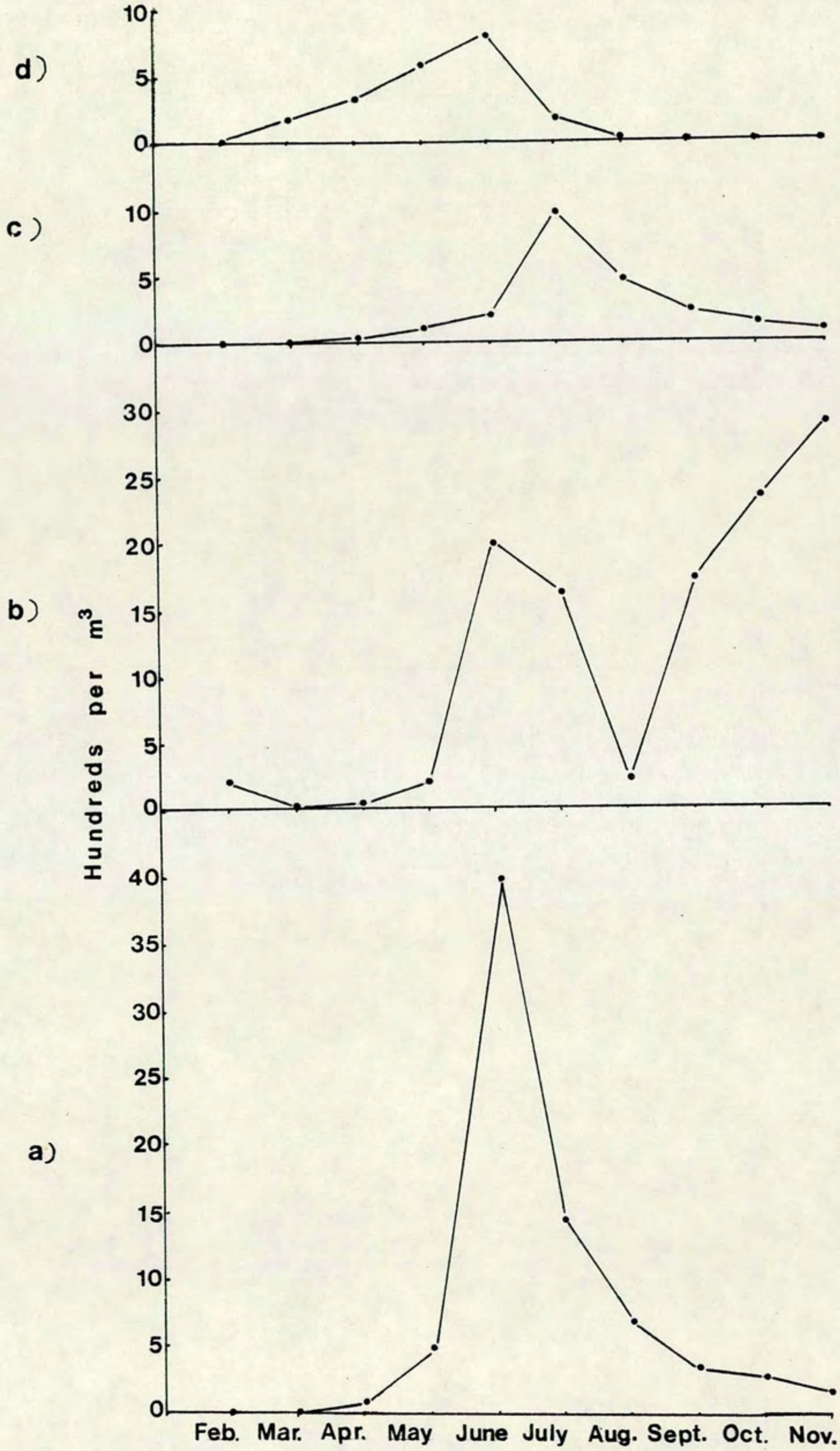


Fig.III.3 - Monthly variation in the number of Daphnia hyalina (a), Bosmina coregoni (b), Ceriodaphnia reticulata (c) and Holopedium gibberum (d).

Oscillations in Cladoceran populations are mainly affected by water temperature and food availability. Rise in temperature increases the rate of moulting and production of broods (ephippia), whereas increase in food supply affects the rate of development of the population by increasing fecundity. Decreases in food supply cause a reduction in the replacement of adults. These effects are not immediate and the extension of the lag period is one of those responsible for the population oscillation.

Oscillations are quite variable among species. However, there is a general trend common to all species. Usually, the population is low in winter and starts to increase after the rise of temperature and increase in food-supply in spring. After reaching peak densities in summer, numbers reduce mainly due to reduction of food-supply, shifts in the quality of food to less palatable species, predation by other zooplankters and fish.

Masses of dead Cladocera were observed in July and August which suggests high mortality during this period.

Presence of ephippia in Cobbinshaw suggests that ephippial females are responsible for the replacement of Cladocera all the year round. Nevertheless, some Cladoceran females (for example in <u>Daphnia</u> <u>hyalina</u>) have the capacity for producing eggs requiring fertilisation, which can withstand drying and freezing and hatch when suitable conditions occur.

Cladocera feed mainly by filtering food particles with their setae, and microscopic algae are among the most important food-items. Thus, there is a close relation between their feeding habits and the concentration of phytoplankton in the lake. Haney (1973) found that in Halls Lake (Canada), Bosmina and Holopedium were the dominant zooplankters and that in the autumn the former dominated the total grazing due to their numerical superiority. Porter (1973) found that an increase in the number of grazing Cladocera and Copepoda produce a decrease in Cryptomonas and certain diatoms and the increase of Sphaerocystis and Anabaena (the latter considered an unpalatable species for Copepoda and Cladocera).

The literature shows that, in general, Cladocera and Crustacea avoid feeding on blue-green algae and presumably their numbers are not related to the oscillation of Aphanizomenon and Coelosphaerium in Cobbinshaw Reservoir. Infante (1973) observed that Asterionella was ingested more readily and assimilated more easily by Cladocera and Copepoda than other diatoms. Such an observation suggests that in Cobbinshaw Reservoir the population level of Asterionella could be related to predation by Cladocera and Copepoda. However,there is no direct evidence to support this.

No attempt has been made to classify Cobbinshaw Reservoir in terms of its zooplankton population. Many works suggest that because of the cosmopolitan characteristics of some zooplanktonic species, they are of little use as indicators of water quality . However, some authors, for example Maitland et al.(1981) disagree with this as they observed correlations of environmental features and diversity and abundance of the zooplanktonic crustacean in large Scottish lakes.

It is also difficult to relate Cobbinshaw Reservoir's zooplanktonic composition to water quality. However, the reservoir is obviously quite productive which reflects its almost eutrophic condition. Feeding relationships between perch and planktonic Crustacea, discussed in Chapter V, show selectivity for size and suggest the existence of a balance in such interaction, with strong predation by perch and a regular replacement of the zooplankton.

Regarding size of the zooplanktonic organisms,, it was observed that Daphnia hyalina was the biggest organism with sizes ranging from 2.2mm to 3.4mm (mean=2.8mm). Cyclops strenuus abyssorum was the second largest organism with a mean size of 1.3mm (range: 1-1.5mm). The other organisms have the following mean sizes: Ceriodaphnia reticulata (1.1mm), Holopedium gibberum (1.0mm), Bosmina coregoni (0.7mm), nauplius larvae and rotifers (0.6mm).

Table III.2 shows the average size of each organism and Fig.III.4 shows the mean value and ranges observed in adult Copepoda and Cladocera. The range in size is probably due to the female being larger than the male. Daphnia hyalina, the largest organism, was that consumed most by trout and perch. Rotifers, in spite of their large numbers were too small to be of interest to large perch and trout. Thus, they were ingested only by very young perch larvae. Such observations suggest that for planktivorous fish the size rather than abundance of prey is more important.

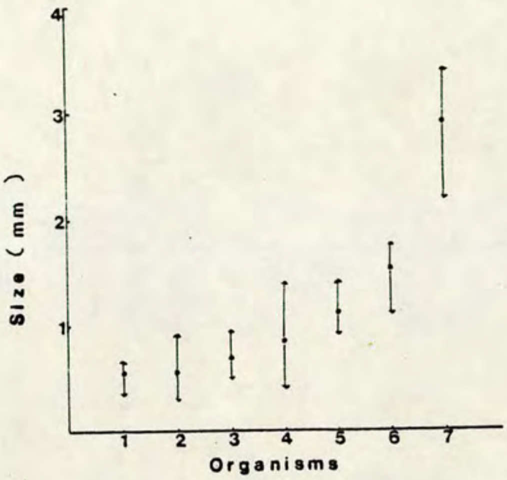


Fig.III.4 - Length class variation in Zooplankton from Cobbinshaw Reservoir.

Various relevant observations have been made of the feeding behaviour of planktivorous fishes. Ivlev (1961) found that the Cyprinid Alburnus alburnus preferred Daphnia, Bosmina and Diaptomus in that order, althoug Bosmina is smaller than Diaptomus. Brooks (1968) found that Diaphanosoma brachyurum (Cladocera) was fairly common in Lake Maggiore (Italy), but was not eaten by planktonivorous fish. The same author speculating about both his own observations and those of Ivlev (1961), suggested that Diaptomus and Diaphanosoma brachyurum could escape the attention of fish due to their habit of hanging relatively immobile from their large antennae and of making sudden jumps, in contrast to the jerky movements that characterize the locomotion of Daphnia and Cyclops and which may be registered in the optic field of the fish (Lindström, 1955).

The size of zooplanktonic prey is important because planktivorous fishes use sight to search for their food. Brooks (1968) observed that many planktivorous fishes rapidly lose their interest in planktonic organisms as the size of the latter decrease toward 1mm.

Thus, any mechanism that would reduce the size at maturity to about 1mm or slightly below would be of considerable adaptive value. Seasonal polymorphism usually observed in Cladocera is also considered by Brooks (1968) as another defence mechanism against predation. In Daphnia, for instance, the helmets reach their tallest size when individuals are producing eggs, the period in which the visible part of the body is at its annual minimum size.

III.3.3 **Bottom fauna**

Composition and distribution of invertebrates

The main bottom fauna organisms found in Cobbinshaw Reservoir were:

1)Crustacea: Asellus aquaticus (L.) and Gammarus pulex (L.)
2)Insecta - Trichoptera: Anthripsodes sp, Limnephilus sp and Mystacides sp.
3)Insecta - Chironomidae: mainly larvae and pupae of Chironomus sp.
4)Mollusca - Pisidium sp, Limnea pereger (M) and Potamopyrgus jenkinsi (S.).

These organisms were the most important because of their abundance and frequency of occurrence. Furthermore, they constitute, with the exception of Potamopyrgus jenkinsi, the main items in the diet of perch and trout.

Other organisms less important because of their sporadic occurrence and low number were treated together in this as 'others'. Among them are:

1)Coelenterata (Hydra);
2)Platyhelminthes - Turbelaria (planaria);
3)Nematoda
4)Oligochaeta (particularly Tubifex tubifex and leeches (Glossiphonia sp);
5)Arachnida - Araneae and Hydracarina (water mites - Hydrachnellae);
6)Insecta: Coleoptera (mainly Hydrophilidae and Dytiscidae,e.g., Platambus maculatus (L.); Hemiptera (Corixa faleni (F.); Ephemeroptera (Caenis sp); Neuroptera (Sialis lutaria (L.);
7)Mollusca: Valvata sp.

Some organisms recorded in the zooplankton were also observed among the bottom sediments particularly Daphnia hyalina, Cyclops abyssorum and Chidorus ovalis. Three shells of the bivalve Anodonta cygnaea were collected during the work. However, they were empty and there is no further evidence to support the statement that this species is part of the bottom fauna of Cobbinshaw Reservoir as proposed by Boyd (1975).

Trial sampling was carried out in June 1981 before setting up the sampling programme proper. A close relationship between distribution of organisms and bottom substrata was observed. The area of black muddy bottom is the poorest. Here the fauna consists mainly of Tubifex tubifex, chironomid larvae, Pisidium sp. and a few specimens of a Mystacides sp. This poor bottom fauna was also observed in the muddy littoral area near the dam on both right and left banks (Fig.II.4, Chapter II).

The area with yellow mud and gravel has also a sparse bottom fauna with only a few snails (Lymnea pereger) and Oligochaeta (Tubifex tubifex).

The transition area between the black muddy and littoral gravelly areas, particularly the area covered by Potamogeton spp, shows a large number of organisms with a predominance of Pisidium sp., Asellus aquaticus, Limnephilus sp, chironomid larvae, Tubifex tubifex and a few Valvata sp.

The richest area is the littoral area with gravel, sand and aquatic plants. A large number of organisms occur and is the most important source of food organisms for the fish. In this area the bottom fauna varies from substratum to substratum according to the vegetation present. Chironomid larvae and Arthripsodes sp. are widely distributed. Potamopyrgus jenkinsi predominates in the area covered by Equisetum palustre. Gammarus pulex predominates in areas with Chara sp. and Elodea canadensis. Asellus aquaticus is the dominant organism in areas with few submerged plants, particularly those close to the line of Potamogeton natans distributed near the shore.

Length-class frequency

Figure III.5 shows the frequency of occurrence of different length classes in the total of organisms collected. There was a predominance of organisms between 0 and 0.5cm; similar extreme abundance of small organisms and relative rarity of larger have been described by other workers, e.g Schoener & Janzen(1968), Werner(1977) and Mittelbach (1981).

The large numbers of Potamopyrgus jenkinsi is an important factor affecting the abundance of 0-0.5cm - length-class. In October, it reached a peak of 3000 individuals per m^2 in one single collection. In order to demonstrate the importance of this organism a diagram showing the length-class frequency without P.jenkinsi is shown in Figure III.6

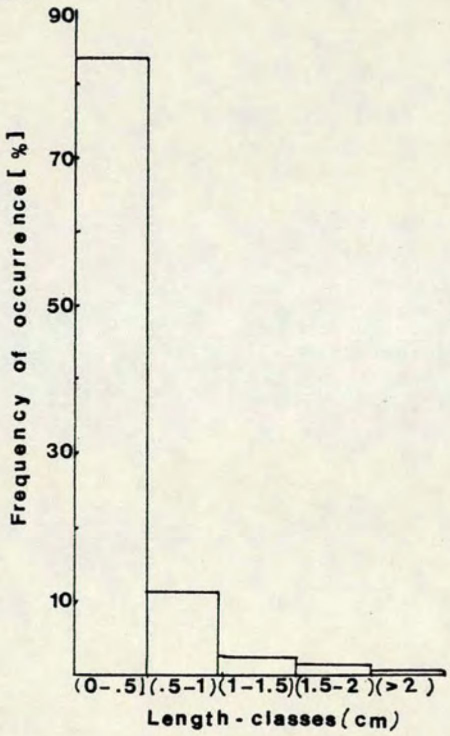


Fig.III.5 - Length-classes frequency (%) of total benthic invertebrates collected.

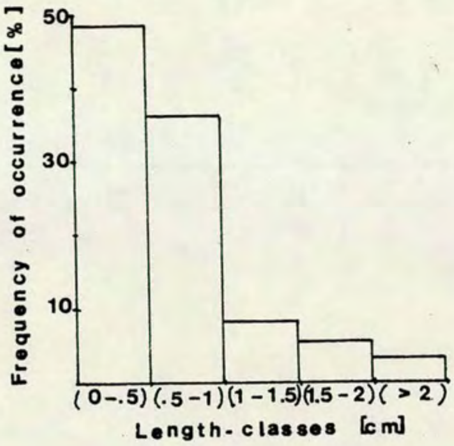


Fig.III.6 - Length-classes frequency (%) of benthic invertebrates excluding Potamopyrgus jenkinsi.

Seasonal Pattern of abundance and controlling factors

The muddy area showed a predominance of Tubifex tubifex all the year round while from April to July chironomid larvae were also recorded. As this area is poor in the number of organisms present and presumably not very important as a food source, the sampling was concentrated in the littoral area (see Table III.3a)

Table III.3b shows the mean number of individuals collected in each month. The high standard deviation shown for each organism suggests that these figures should be taken only as a rough approximation of the actual abundance. This is due to the distribution of organisms in the sampling stations. In some areas they were

Table III.5a Monthly variation in the number of benthic invertebrates from the black muddy area collected in a single Ekman grab.

Organisms	Crustacea		Trichoptera			Diptera		Mollusca			Annelida
	Asellus aquaticus	*Gammarus pulex*	*Arthripsodes* sp	*Limmephilus* sp	*Mystacides* sp	Chironomidae larvae	Chironomidae pupae	*Potamopyrgus jenkinsi*	*Lymnea pereger*	*Pisidium* sp	*Tubifex tubifex*
Month											
February	0	0	0	0	0	0	0	0	0	0	5
March	0	0	0	0	1	0	0	0	0	0	8
April	0	0	0	0	1	1	0	0	0	0	10
May	0	0	0	0	1	1	0	0	0	0	15
June	0	0	0	0	0	2	1	0	0	0	18
July	0	0	0	0	0	1	0	0	0	1	16
August	0	0	0	0	0	0	0	0	0	2	15
September	0	0	0	0	0	0	0	0	0	4	9
October	0	0	0	0	0	0	0	0	0	0	5
November	0	0	0	0	0	0	0	0	0	0	5

Table III.3 - Monthly variation in the mean number/m^2 ($\pm$ s) of benthic invertebrates from Cobbinshaw Reservoir

Organisms	Crustacea		Trichoptera			Diptera		Mollusca				
	Asellus aquaticus	*Gammarus pulex*	*Arthripsodes* sp	*Limmephilus* sp	*Mystacides* sp	Chironomidae larvae	Chironomidae pupae	*Potamopyrgus jenkins*	*Lymnea pereger*	*Pisidium* sp	'Others'	Total
Month												
February	2.0±1.0	8.5±7.5	10.5±0.5	0	0	0	0	1.5±1.5	0	0	5.5±4.5	28
March	1.0±1.0	10.0±2.0	15.5±1.5	0	0	1.0±0	0	7.0±0	0	0	10.0±3.0	44.5
April	2.2±1.3	9.4±9.9	17.2±14.0	0.8±0.7	0	1.2±0	0	9.4±9.6	0.4±0.5	0	2.8±1.9	43.4
May	3.0±3.0	9.0±7.6	3.0±1.9	1.2±1.6	0.20±0.4	2.2±0.4	0	10.2±14.9	0.5±0.5	0	26.5±28.8	55.8
June	7.2±6.3	41.8±42.0	6.7±9.6	0.9±0.8	0	27.2±34.0	0.8±1.4	23.1±15.0	0.5±1.5	2.2±4.0	18.8±9.9	129.2
July	35.5±39.4	51.0±27.7	7.2±8.2	0.2±0.4	0	8.2±11.4	1.5±1.1	28.2±25.3	0.70±0.4	2.7±0.4	44.0±41.3	179.2
August	31.8±33.1	43.1±38.6	4.4±4.3	0.6±0.6	0.2±0.4	4.5±5.8	0.2±0.6	167.9±341.6	10.0±20.1	3.7±4.4	37.0±29.9	303.4
September	47.0±1.7	82.6±52.0	4.6±2.9	1.3±1.2	0	1.0±1.4	0	962.3±710.0	7.0±4.2	33.7±26.6	37.3±32.3	1176.5
October	4.3±8.8	75±73.2	29.9±10.9	1.1±2.0	0.10±0.2	0.8±1.8	0	527.8±1085.0	6.9±15.0	13±3.1	15.0±16.4	673.90
November	3.0±1.2	23±19.0	21.0±20.0	0	0	0	0	13.6±12.3	3.0±3.5	1.0±1.4	12.0±8.5	76.6

s = standard deviation

abundant, in others scarce or absent.

Figure III.7 shows the monthly variation in the mean number of organisms per m^2. Numbers increased after April to reach a peak abundance in September, decreasing afterwards. As discussed later the increase in numbers from the spring to the summer is related to improving environmental conditions (particularly increase in water temperature) and to the reproductive cycle of each group. The decrease after September, on the other hand, is related to impoverishment of environmental conditions and to associated natural mortality. The decomposition in soft water, like Cobbinshaw, is expected to be very rapid, particularly of snail shells.

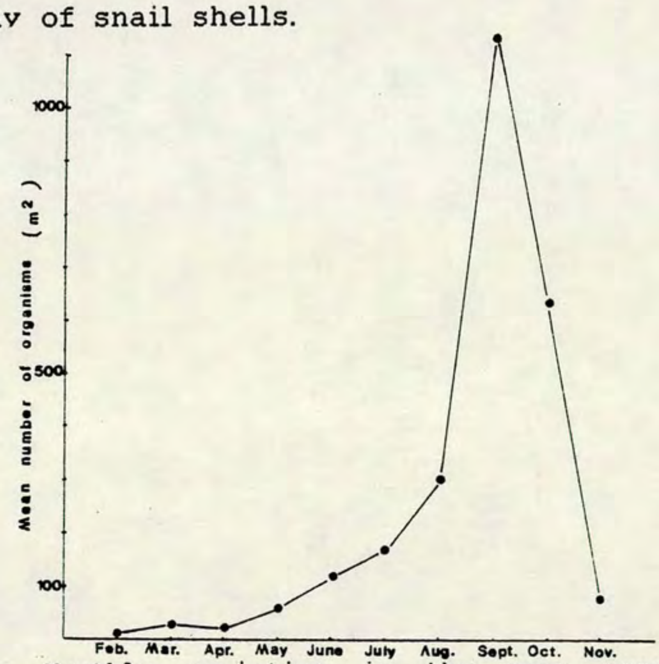


Fig.III.7 - Monthly variation in the mean number of benthic invertebrates/m^2 from Cobbinshaw Reservoir

Figure III.8 shows the monthly percentage composition of samples of benthic invertebrates from Cobbinshaw Reservoir. February was dominated by Trichoptera larvae, Gammarus pulex and 'others', which also dominated in March together with Mollusca. In May there was a predominance of 'others', besides Gammarus pulex and Mollusca, with an abrupt decline of trichopteran larvae due to hatching and predation. In June the dominance of Mollusca, Gammarus pulex and 'others' continued.

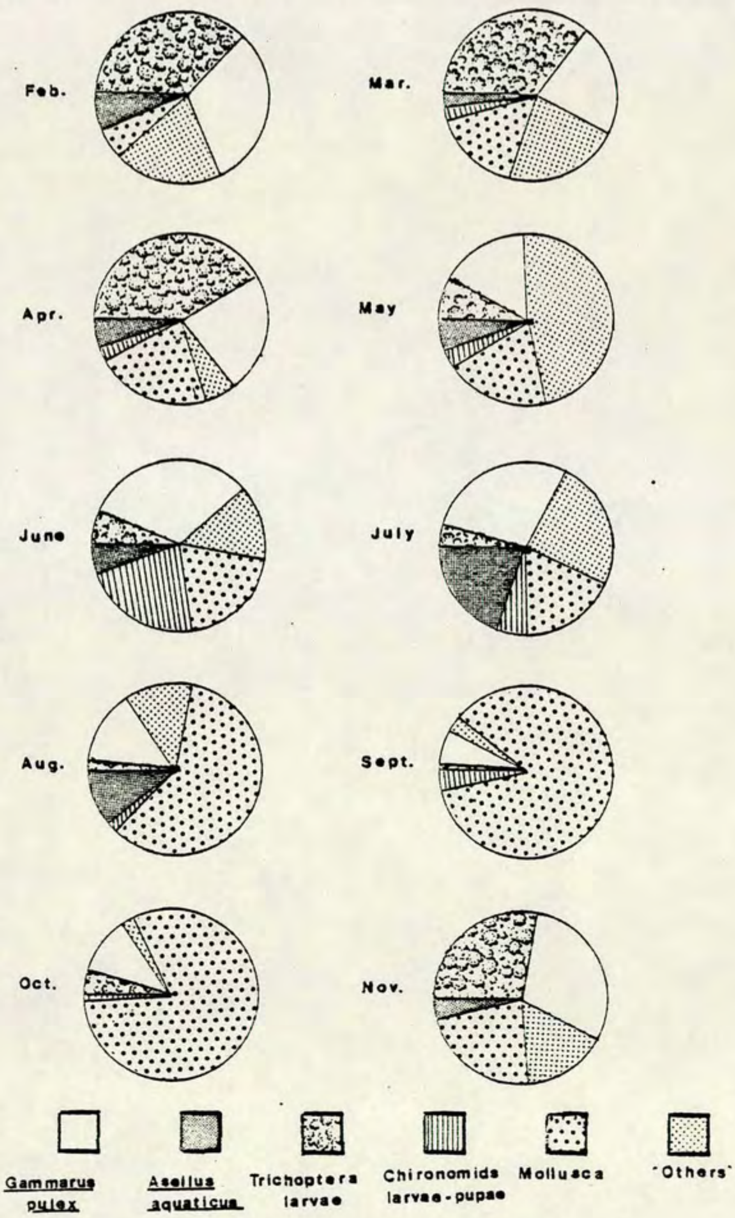


Fig.III.8 - Monthly variation in the percentage composition of total benthic invertebrates from Cobbinshaw Reservoir. Each circle represents 100%.

However, chironomid larvae and pupae appeared as another abundant group. In July, chironomid abundance was replaced by Asellus aquaticus. From August to October there was a complete dominance of Mollusca. In November Trichoptera larvae re-appeared as a high percentage of the total population followed by Gammarus pulex, Mollusca and 'others'.

As discussed in Chapter V, only a few of the organisms mentioned represent important items in the fish's diet. These organisms were Gammarus pulex, Asellus aquaticus, Trichoptera larvae, chironomid larvae and pupae, and Mollusca (Lymnea pereger and Pisidium sp.). Figure III.9 shows the monthly variation in the percentage composition of these organisms in the bottom fauna, when they are separated from those not (or rarely) consumed by the fishes.

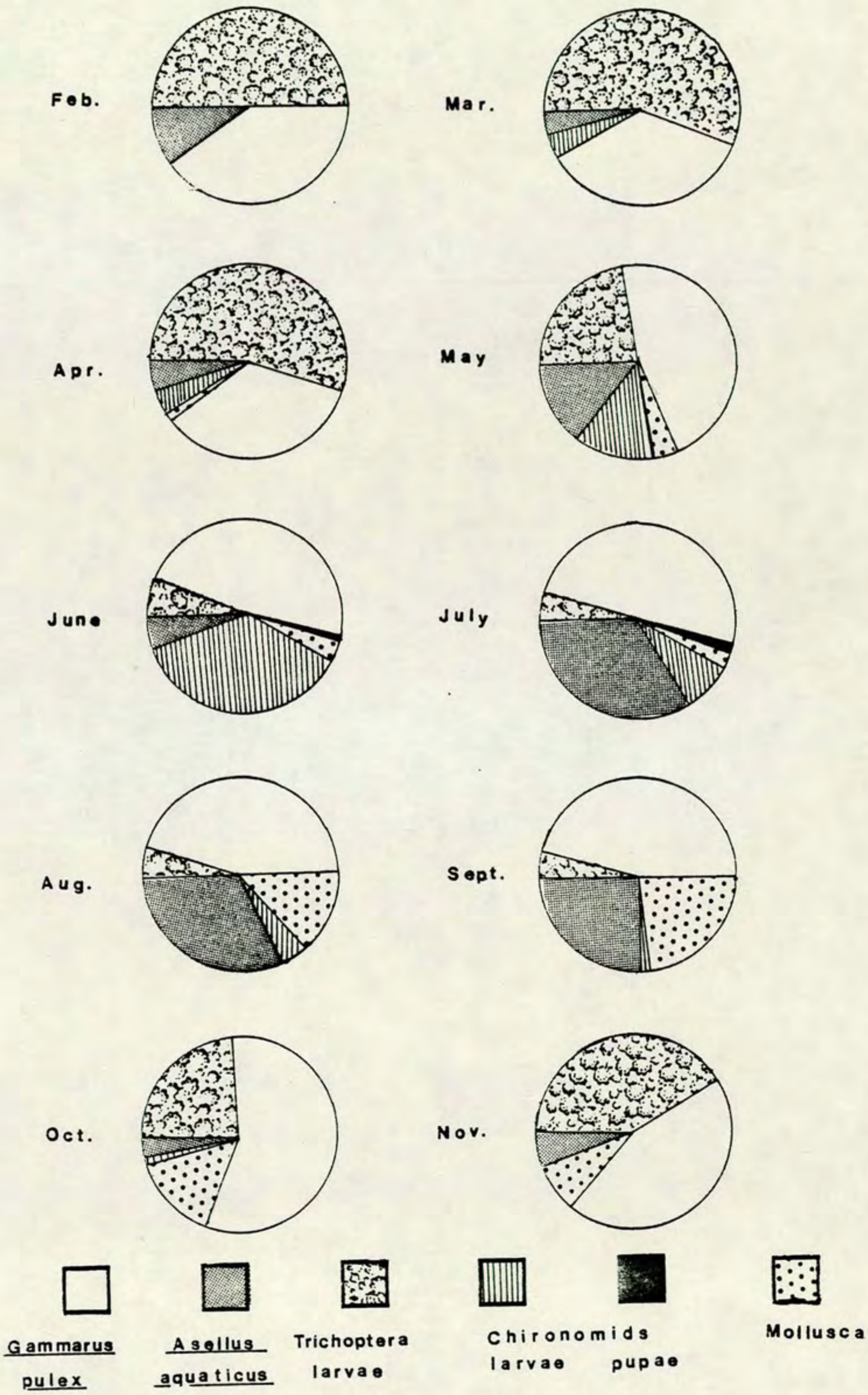


Fig.III.9 - Monthly variation in the percentage composition of the main benthic invertebrates used as fish food in Cobbinshaw Reservoir. Each circle represents 100%.

Gammarus pulex was the only species available in appreciable quantities all the year round. Trichoptera predominated from February to April, were abundant in May, October and November. Asellus aquaticus showed a peak abundance in July, August and September, Chironomidae in May and June, and Lymnea pereger and Pisidium sp. from August to October.

Considering their abundance and importance as fish food, benthic invertebrates were ranked as follows: a)Asellus aquaticus, b)Gammarus pulex, c)trichopteran larvae, d)Chironomidae, e)Potamopyrgus jenkinsi, Lymnea pereger, f)Pisidium sp. and g)'others'. The patterns of seasonal abundance and composition of each group was characterized as follows:

a)Asellus aquaticus: among organims eaten by fish this species was the second most abundant in the bottom fauna (Table III.3). Its numbers increased from April to July, decreased slightly in August and reached their peak in September (47 individuals per m^2). The maximum number collected at one station was 227 individuals per m^2. The length-classes varied from 0-0.5cm to 1.5-2.0cm, with a predominance of the first.

Asellus is the only genus of order Isopoda considered as a true inhabitant of fresh water (Hynes et al.1960). Only three species have been recorded from the British Isles: A. aquaticus, A. meridianus and A. cavaticus. The first two are widely distributed and occupy the same type of habitat whereas the latter is restricted to Southern England and

Wales (Moon 1957a,b).

The latter author suggested that neither physical nor chemical factors could explain the distribution of A. aquaticus in Windermere and concluded that it was introduced by man and that human activity is the main factor responsible for its distribution. Therefore, it is possible that its presence in Cobbinshaw Reservoir is also related to human activity, considering the artificial conditions prevailing.

A. meridianus was described by Moon (1957a,b) as a more sub-littoral than littoral species. Since the sub-littoral area of Cobbinshaw Reservoir is composed of black mud - an environment unfavourable to A. meridianus, and as the latter species is unable to compete with A. aquaticus in the littoral area (Moon,1957a), presumably competition for habitat could be a cause of the absence of A. meridianus in Cobbinshaw waters.

The seasonal abundance of A. aquaticus in Cobbinshaw Reservoir seems to be mainly related to its reproductive cycle, which, however, is not completely understood (Moon,1957b). It is unlikely that food is limiting factor as they feed mainly on silt, fine debris and bacteria covering stones and leaves (Moon,1957a), all of which are abundant in Cobbinshaw.

The last author suggested that in Windermere Asellus was eaten by fish, but he found no correlation between their distribution and fish movement. In Cobbinshaw, predation by fish (particularly trout) is probably an important parameter affecting the population of A. aquaticus. This aspect is discussed in chapter V. It was also observed that parasitism by Acanthocephala (Echinorhynchus truttae) is another important factor affecting A. aquaticus mortality.

b)Gammarus pulex: this species is common in Cobbinshaw Reservoir all the year round (Table III.3). It was the most abundant of those in the bottom fauna used by fish, apart from in April when trichopteran larvae were present in greater numbers.

The population of G. pulex, like those of A. aquaticus, increased from April and reached a peak in September (82.6 individuals per m^2). This maximum is low when compared with the figures for very productive streams recorded by other workers. Macan & Mackereth(1957), for instance, found 200 individuals per m^2 in Ford Wood Beck (England) and Berg (1948) found 2054 individuals per m^2 in the River Susaa (Scandinavia). However, although the mean densities for Cobbinshaw were much lower than these figures, samples were found with very high numbers, e.g. a sample with 227 per m^2 in October 1982. The reason for this is the habit of G. pulex for concentrating in great numbers in areas of gravel, and samples from such areas show figures above the mean.

Presumably, the areas with high densities of G. pulex observed in Cobbinshaw constitute important feeding grounds for perch, as this species is the most important food item for perch in the lake, as shown in Chapter V.

Lengths of G. pulex varied from 0-0.5cm to 1.5-2.0cm, with a predominance of the first size group. Representatives of different length-classes were found all the year round.

The observed variations in number and size of G. pulex are associated with its reproductive cycle, which is complex and includes the presence of two groups with different breeding patterns in the population. The annual cycle of these groups is described by Hynes (1955b) as follows. In the first group females begin to produce eggs in December and the first young individuals appear in early March with numbers increasing until June. Maturity of the young occurs in July and August and breeding takes place through August and early September. Following this there is a halt in breeding which recommences in December and goes on until the spring with the individuals presumably dying in April or May. The second group includes organisms that are born in the summer, have a short resting period in the winter and overwinter as juveniles, mature in March, breed from April to June. Many individuals are also recorded by Hynes (1955) as dying during winter - they presumably constitute members of the first group which do not survive for the pre-spring breeding, together perhaps with second group juveniles.

The occurrence of breeding at different periods of the year is related to the influence of water temperature on maturity. In the summer (at temperatures from 10°C to 15°C) organisms take 3-4 months to mature, whereas in the winter (at temperatures from 5°C to 10°C) they take about 7 months (Hynes 1955).

Predation by invertebrates is considered by Macan & Mackereth(1957) as a negligible factor affecting the population numbers of G. pulex, however, they regard predation by fish as important. In Cobbinshaw Reservoir predation by fish (mainly perch) is presumably among the main causes of G. pulex mortality.

c)Trichopteran larvae: these organisms are quite abundant in Cobbinshaw Reservoir particularly in October when they reach a maximum of 378 individuals per m^2 at a single station (Table III.3). In April a mean of 18 individuals per m^2 was observed. The numbers decreased markedly in May, increased in June, decreased again until August and increased again to reach a peak in October (82.6 individuals per m^2). The latter figure represents the period at which the eggs hatch and a large number of small larvae (usually less than 0.3cm) disperse on the lake substrata searching for food and material to build their cases. Usually, the adults derived from these larvae hatch in the summer.

Trichopteran larvae constitute an important food for trout in Cobbinshaw Reservoir, particularly in the spring, and it is possible that the lower numbers observed from February to June, when compared to the highest values in October, are related to predation by trout at this period of the year.

d)<u>Chironomidae</u>: the numbers of chironomid larvae increase from spring to summer and then decline until they disappear in November (Table III.3). Their mean peak dominance occurs in June (27.2 individuals per m^2) with a maximum of 62 individuals per m^2 in a single sample. At this time they were the second most abundant organism in the bottom fauna, most of them belonging to the 0-0.5 length-class.

Attempts to classify the larvae were not successful, however, it was observed that most belonged to the genus <u>Chironomus</u>. The larvae showed a variety of colours (white,brown,green,red) and such colouration is reported to be related to larval behaviour. Imms (1957) suggested that the green colour is a characteristic of larvae which feed at the water surface, whereas the red colour is a property of the 'blood worms' which possess a kind of haemoglobin in their blood. Such haemoglobin facilitates life in environments poor in oxygen and 'blood worms' are also found on muddy substrata.

The numbers of chironomid pupae reached its peak in July (1.5 individuals/ m^2 and is of very short duration. Most of the pupae were of 0-5cm, however, some of 2-2.5cm were recorded.

The observed variation in number of chironomid larvae and pupae in Cobbinshaw Reservoir is closely related to the reproductive cycles of these organisms. Adults emerge in warmer water throughout the summer and live for one to two months. The eggs, enveloped in a transparent mucilage, are laid in water and hatch a few days later. The larvae live on the bottom and some are free while others spin a loose web of bottom particles and silk in order to make a case. The larval stage comprises most of the life-span of chironomids. After overwintering larvae become very active and pupating starts by May. The pupal stage is of very short duration and some movement occurs inside the case. Before adult emergence the pupae make their way to the water surface where they break the pupal skin and fly away.

Wetzel (1975) pointed out that Diptera are the major constituents of the benthic invertebrate fauna and that Chironomidae are the most abundant among them. Density in running waters is reported to be higher than in still waters and in this context the density recorded for Cobbinshaw is comparatively low. Many factors could be involved in producing this 'low' figure.

Probably the most important of these was mere sampling error, particularly because of the behaviour of chironomid larvae of living among detritus and inside cases. However, predation by perch on chironomid larvae and pupae is very high in Cobbinshaw Reservoir and presumably is important in reducing chironomid numbers. It seems unlikely that any chemical or physical characteristics of Cobbinshaw water are involved in producing the comparatively 'low' number of chironomids.

e)Potamopyrgus jenkinsi and Lymnea pereger are the principal representatives of the Gastropoda in Cobbinshaw Reservoir.

The first of these is important because of its abundance (Table III.3) and the second because of its contribution to the diet of trout.

Numbers of Potamopyrgus jenkinsi increased from February (1.5 individuals/ m^2) to September when they reached their peak (962.3 individuals/ m^2) with a maximum of 3000 individuals/m^2 in a single collection. All individuals were from 0 to 0.5 cm.

Numbers of Lymnea pereger, on the other hand, increased from 0.4 individuals/m^2 in April to 10 individuals/m^2 in August and decreased thereafter. Most organisms were of the 0-0.5cm group, but some belonged to the 1.5-2.0cm group.

Although L. pereger is described by Macan (1960) as the commonest and most abundant species of gastropod recorded in the British Isles, its numbers in Cobbinshaw are relatively low.

The seasonal trend in gastropod numbers is related to their life history. According to Harman (1974) they breed only once a year, in late summer and autumn, and the young overwinter as small individuals which mature in the following spring and summer. Individuals of different size-classes are found all the year round and the population peaks after breeding due to recruitment of young individuals into the population.

Pisidium sp. is the only representative of the lamellibranchs in Cobbinshaw Reservoir, unless it can be established that Anodonta cygnaea is present as a living organism and not just represented by the empty valves which have so far been found. Pisidium was not found until June (Table III.4) and them increased in numbers to reach a peak in September (33.7 individuals per m^2) with a maximum of 68 individuals per m^2 in a single collection.

Hadl (1972) observed that members of the genus Pisidium show different reproductive cycles according to the substratum. Females living in the littoral area, exposed to a large seasonal fluctuation in temperature, are usually gravid in the spring, and breed in the summer when rapid growth occurs. Following this they overwinter. These organisms live for about a year, or slightly longer (Wetzel,1975).

Distribution and abundance of the Mollusca in freshwater are dependent on various environmental conditions. According to Boycott (1936) ideal conditions for gastropods are a large volume of moderately warm calcareous water flowing not too rapidly over a shallow bottom with a moderate growth of plants and without suspendend inorganic matter or organic pollution. Lamellibranchs prefer areas of relatively stable substratum, low silt turbidity and no pollution (Reid,1961).

Presumably the distribution of gastropods and lamellibranchs in Cobbinshaw Reservoir, i.e., high density in some areas and total absence in others, are related to these environmental requirements. In fact, according to Boycott (1936) if all the conditions are present a large number of species is likely to be found. If any characteristic is absent the number of species present is less. Nevertheless, a high level of one factor may compensate for deterioration of another.

Macan (1960) classified Mollusca in four groups according to the water characteristics: (1)brackish water species, (2)species limited in distribution, (3)hard water species, (4)soft water species. In this classification Potamopyrgus jenkinsi, Lymnaea pereger and Valvata cristata are included in group 4, Valvata macrostoma is in group 2.

Armistead (1915)observed a complete absence of Mollusca in Cobbinshaw Reservoir, which was regarded by him as due to lack of weeds. Today the lake has dense weed beds and a large number of Mollusca, particularly Potamopyrgus jenkinsi. An interesting aspect in this context is that the first British record of this species was in 1883 in brackish water in the River Thames estuary and 10 years later it was found in fresh water (Macan,1960). Nowadays it is widespread in the British Isles in both environments (Ellis,1951). It is quite difficult however, to account for the presence of P. jenkinsi in Cobbinshaw Reservoir as this lake is an upland reservoir and it seems that these organisms arrived there after Armistead's 1915 report,i.e. about 100 years after the construction of the dam.

Although it is not the aim of this work to discuss the origin of the Cobbinshaw bottom fauna, it is interesting to refer to the study of Bondensen & Kaiser (1949) who suggested that birds may eat *P. jenkinsi* and vomit them up later, thus providing an important mechanism for distributing the species. Possibly *P. jenkinsi* has reached Cobbinshaw in this way.

f)Other organisms ('others'): a list of these organisms is presented in the section on composition. Considering the aims of the present investigation and the variety of these organisms, it is not necessary to discuss the abundance and distribution of each species in detail. As shown in Table III.4 higher values were observed from May to September with a peak dominance in July following more or less the same seasonal trend as the organisms already discussed. The group is dominated by Annelida (particularly Tubificidae), the size group of which ranges from 0-0.5cm to 4-4.5cm. The latter length-class represents the biggest organisms recorded in the bottom fauna. Abundance of tubificids in lakes and streams is related to increasing organic pollution and low levels of oxygen. Presumably the large amount of these organisms in Cobbinshaw is related to the presence of organic material (particularly plants debris) in the bottom sediment, where they were most abundant.

Hynes (1970) discussed the factors regulating the occurrence and abundance of benthic invertebrates. He concluded that the most important of these are current speed (particularly in streams), temperature, substratum (including vegetation), and dissolved substances. However, he suggested that many other factors are involved. Among them are liability to drought, food availability, competition between species, shade zoogeography, dissolved oxygen, salinity, acidity, hardness, spates, ovipository habits and adjoining land. Many of these factors were mentioned in the present discussion and regarded as correlated with the distribution of benthic invertebrates in Cobbinshaw.

The distribution of invertebrates in Cobbinshaw Reservoir and elsewhere are apparently correlated to the three ecological principles of Thienemann (1954) viz: 1)The number of species is directly correlated with the diversity of the environmental conditions in a locality. (2)The more the conditions deviate from the normal, the smaller is the number of species and the greater the number of individuals of a single species. (3)Richness and stability of a community are directly related to stability of the environmental conditions of the locality.

The number of species of invertebrates observed in Cobbinshaw, particularly those of interest to fish, is relatively low when compared with oligotrophic lakes and streams which are typically salmonid waters. However, the actual number of organisms is comparatively large which suggests that this lake is very productive, despite the littoral area (the richest area) being small when compared with the large black muddy bottom area. Such a characteristic classifies Cobbinshaw as eutrophic according to Maitland (1978). However, as previously discussed, many other characteristics have to be considered to find the best classification for any particular water.

Hellawell (1978) pointed out that invertebrates are very important in establishing levels of water quality in terms of pollution indices and diversity indices. The first of these indices refers to the response of the organisms to pollution and the second consists of the number of pollution-indicator species present.

Many biotic indices are used in the literature (e.g.,Lothian index-Graham, 1964,1965; Trent biotic index-Woodiwiss,1964; biotic score-Chandler,1970, etc.).

According to the Lothian index, Cobbinshaw Reservoir is in general characterized by clean water (index 1) as shown by the presence of Trichoptera and Ephemeroptera (_Caenis_ spp). Nevertheless, in some areas the presence of a large numbers of _Asellus aquaticus_, _Potamopyrgus jenkinsi_ and _Chironomus_ spp. gives a classification in category 3, which indicates some organic pollution - this is due to the decomposing organic material present on the bottom.

According to Hellawell (1978) the Lothian Index is derived from a consideration of two effects of pollution: the reduction in community diversity and the progressive loss of certains groups. It comprises five classes which vary from index 1 (clean water) characterized by the presence of Plecoptera, Trichoptera and Ephemeroptera in the bottom fauna to index 5 (toxic water) characterized by the total absence of macroinvertebrates.

IV PERCH GROWTH STUDIES

IV.1 Introduction

IV.1.1 Definition of growth

Variation in growth pattern is a characteristic of fundamental importance in fish biology. According to Nikolsky (1978) a fast growth rate results in many large individuals in the population and thus higher protection against predators. However, to achieve this an abundant food supply must be available. On the other hand, if growth is slow the individuals are smaller and easier prey for predators. In this case, however, loss due to predation may be compensated for by increasing reproductive capacity.

Before the onset of maturity the food supply is normally used for linear growth. Afterwards it is used for maturation of gonads, for accumulation of fat for overwintering and for general maintenance of the body. So, usually there is fast early linear growth while later such linear growth pratically ceases (Nikolsky, 1978).

According to Bagenal & Tesch (1978) studies on the age and growth of fishes started some 250 years ago. There is, however, considerable controversy about what actually constitutes growth. Thompson (1942) and von Bertalanffy (1960), for example, suggested that somatic growth of an organism is related to increase in bulk, which is accounted for by increase in metabolically active tissue such as muscle, liver, nerves, endocrines, etc. Love (1970) attributed growth to increase in cell numbers whereas Greer-Walker (1970) and Greer-Walker & Pull (1975) suggested that increase in diameter of white muscle fibres is the main factor responsible for growth in fishes. Weatherley & Rogers (1978) discussed the previous statements and concluded that 'growth might be holistically viewed as the entire suite of accretions and products of an organism resulting from metabolism, which may increase not only the organism's bulk over time, but also the scope and magnitude of its internal dynamics, plus its structures or its potential for forming new ones'.

In some species that are adapted to living under unfavourable conditions the population consists of few age groups. In these cases replacement of individuals occurs rapidly. On the other hand, other species are adapted to living under conditions of a relatively stable food supply and the individuals are replaced slowly. So that their populations are made up of age-groups from several decades.

According to Nikolsky (1978) variation in age and size-composition of population is influenced by the success of separate year-classes; by predators and epizootics which cause the mortality of young fishes and adults, by abiotic conditions which may lead to the death of age groups during the overwintering period and by the intensity of fishing.

IV.1.2 Determination of fish growth

Usually, the age of fish is determined from the scales, otoliths or other bones. According to Nikolsky (1978), the Dutch naturalist Leenwenhoek in 1684 was the first to demonstrate the use of such structures to age fish. More recently many investigators have developed the methods which have been reviewed by Chugunova (1959).

The basis of these methods is the periodicity in the growth of fish related to the seasons of the year: this is reflected in the scales and various bones. When growth is fast during the summer an opaque zone is laid down in bone and this gradually fades into a narrow transparent winter zone, which in turn ends abruptly with a sharp line of discontinuity between it and the next summer zone - this discontinuity is used to assess the age.

There was originally much discussion about the accuracy of these methods for ageing fishes, but this has largely disappeared as a result of the many successful investigations which have shown the validity of the method (e.g. Monastyrky (1926), Petrov & Petrushevsky (1929), Zamakhaev (1940), Le Cren (1947), Chugunova (1959), Le Cren et al. (1977), Craig et al. (1979).

Le Cren (1947) pointed out that Graham (1929) and van Oosten (1929, 1941) advanced five lines of evidence to substantiate the accuracy of age determinations made from rings on scales or bones of which three are relevant to the discussion here: (1)' if the rings on the scales of bones are annual formations, examination of their growing edge throughout the year should reveal an annual cycle in the structure seen at that edge'; (2) 'fish can be marked when fry, or at a known age, and then released. When recaptured the number of rings on their skeletal structures should agree with their known age'; (3) 'fish reared in ponds or aquaria are often of known age, and the rings on their scales and bones can be checked against known age'.

To determine the age using these methods one has to consider the following factors, according to Nikolsky (1978): (1) sometimes it is difficult to make a distinction between the larval and the first annual ring. (2) the time at which the annual rings are laid down in fish of different ages varies according to the season. (3) the formation of annual rings can be disturbed by retardation of metabolism and disturbance of feeding, and by unfavourable changes of temperature (although the rings are not formed directly under the influence of temperature).

IV.1.3 Objectives of this chapter

In the present investigation the growth of perch in Cobbinshaw Reservoir was studied by monthly measurements of length and weight for each age-class and the dominant year-class and its influence on the whole population was determined. Condition of the fishes was also evaluated by estimating the condition factor, K, which is described in the next section. Age studies were included in this work as fish feeding varies in different age groups. Furthermore, age composition of the stock, relative strength of the different age groups and maximum life span are parameters of extreme importance in practical fisheries management, as they can lead to assessment of mortality rates and to knowledge of the growth rate of fish.

Data were compared with those of other waters in order to determine relative growth-rates and obtain an idea of the range in environmental conditions.

An extensive literature on perch age and growth structure already exists but it unneccessary to consider it here, since it has already been reviewed by Thorpe (1977b) and furthermore most of the works are discussed in the following sections of this chapter.

IV.2 Materials and Methods

Fieldwork was carried out from April 1981 to March 1983. As the Cobbinshaw Angling Association would not give permission for trout netting or trapping, most of the collection of data had to be restricted to the fishing season, from April to September. An additional constraint was that the weather conditions were very severe in the winter of 1982 and the lake was frozen from December to February.

IV.2.1 **Fish collection**

Sampling stations were concentrated in the large lake as there is neither stocking nor fishing in the small lake (Appendix 4).

Perch, pike and trout were captured by using traps, gill nets, seine nets and rods (anglers) in different areas of the lake. All trout captured with traps and nets were released as data for trout were taken entirely from fish caught by anglers. This procedure followed the instructions of the Cobbinshaw Angling Association administration designed to avoid increases in trout mortality by netting and trapping, as the main objective of the Reservoir is to provide fish for angling.

Trapping

Fort & Brayshaw (1961) recommended the use of a trap for experimental marking, investigating local migrations, reducing stock and catching spawners.

Hellawell (1978) pointed out several advantages of using traps. Among them are: (1) little labour to set and recover; and (2) little disturbance of the habitat and suitability for waters which are too deep to be fished successfully by electrical fishing or where obstacles preclude the use of nets.

The trap used in Cobbinshaw was similar to the Windermere perch trap (Worthington, 1950; Bagenal, 1972a). It was a semi-cylindrical wire cage 0.6m in width, 0.6m in height and 1.6m in length. In one end wall there is a funnel directed inwards for 0.44m to an opening 0.08m in diameter, and in one of the side walls there is a flap door to facilitate recovery of the catch.

Although this trap is recommended for fishing in deep water (down to 6m), it was used in this study in shallow water (up to 2m). The traps were lowered to the bottom on a rope and their positions were marked by buoys. They were emptied daily.

Some studies have been made on the effectiveness of this kind of trap, as it may be selective for fish-size, sex and species. Worthington (1950) observed that in Windermere male perch predominate in traps set in the spring. Fort & Brayshaw (1961) reported the removal of several million perch from Windermere and considered April and May as the 'most lucrative time to trap perch' in that lake. Stott (1970) criticised the low-catching power of perch traps and observed that catches increased up to about 10.5^{o}C and declined at higher temperatures. Bagenal (1972a) suggested that this trap may be a convenient sampling gear for estimating the population age-structure and fish condition and that it is very useful for perch catches. However, he recommended that many traps should be used in order to obtain adequate sampling and consistent results.

Netting

Lagler (1978) defined active netting as fishing with a fabricated mesh that is moved by man or machine (For example, purse seine, haul seine), as contrasted with passive netting where the net is set and left to fish by itself (for example, gill net, trammel net).

More recently, nets have been made of synthetic fibres such as nylon and are very durable because of their greater strength and the absence of rotting. There is a large number of net types and most of them are very efficient for standing waters.

In Cobbinshaw seine nets and gill nets were used.

a)Seine net

Essentially a seine-net is a long bag shaped net which has weights along the bottom, floats along the top, it is placed in the water by various methods and is then drawn in by hauling at both ends. Hellawell (1978) showed that the mesh-size of seine-nets is very important as it limits the size of fish to be captured and strongly influences the effort and speed with which the net is hauled. He considered that one of the most difficult problems in seining is to control the net and avoid lifting of the lead-line from the bottom and sinking of the head-line at the surface.

Among the advantages of a seine-net Hellawell (1978) pointed out that it can be set in deep water and that the catch is usually in good condition and not too strongly selected, except for the lack of the very smallest fish. He considered that it had certain disadvantages namely that(a) it requires several people to haul; (b) it depends on the substratum and (c) on the skill of the operators. He suggested using the net on a firm and smooth substratum and avoiding areas with submerged tree-trunks, boulders or discarded rubbish.

In the present work two seine-nets were used: the first was 100m long with a mesh size of 4cm^2 and a bag with a mesh-size 2cm^2, and the second 150m long with a mesh size of 2cm^2 and a bag with 1cm^2 mesh-size.

b)Gill net

Lagler (1978) described a gill net as a passive net consisting of a single wall of fabric, hung to a float line at the top and lead line at the bottom, which captures the fish by entanglement.

It is highly selective for size of fish and has to be set according to the local conditions.

Kipling (1963) pointed out that a gill net is very selective for size in perch and Frost & Kipling (1967) observed the same for pike.

A major problem in using a gill net is the death of the fish if the collection takes a long time.

Bagenal (1972b) recommended the number of gill nets which should be used in order to obtain an accurate sample of perch and pike. For example, he suggested that if thirteen nets are need for perch, only six would be required for pike.

In the present study two gill nets were used. One 50m long with $4cm^2$ mesh size and the other one 80m long with mesh size ranging from $1cm^2$ to $3cm^2$, from one end to the other.

IV.2.2 **Treatment of the fish**

Preservation and examination of the fish were in the main carried out following Lagler (1978). Perch were preserved in 10% formalin and the following parameters were determined within 24 hours of capture.

Length: perch were measured from the tip of the snout to the distal end of the longer lobe of the caudal fin (total length. Le Cren, 1947).

Lagler (1978) recommended the use of fork length as the most convenient. However, total length was chosen in the present work since it had already been used in most studies with which the Cobbinshaw data could be compared (e.g. Le Cren 1947, 1958; Moriarty, 1963; McCormack, 1970; Le Cren et al. 1977; Craig, 1980).

Weight: wet fish were weighed on a Sartorius balance.

Sex: sex and maturity stages were determined by examination of the gonads. Gonads were weighed with a Sartorius balance.

IV.2.3 **Age and growth**

Age determination of perch was carried out using the opercular bone method (Le Cren, 1947) with some modifications. This method was chosen because there is evidence that it is easier and more reliable for studying the age of perch than other methods (Le Cren 1947, 1958; Craig, 1974b; Le Cren et al.1977; Craig et al.1979).

Le Cren (1947) pointed out that the main evidence in support of annual formation of the rings of the perch operculum came from detailed population studies. Furthermore, the reading of age from the opercular bones of fish up to four years old at least, agree with estimates of age made from length-frequency distributions, and are also confirmed by the occurrence of dominant year classes in successive annual samples'.

The method consists of removing the operculum from the fish by slipping the point of a scalpel under its posterior edge between the opercular and sub-opercular bones. The scalpel is then moved downwards until it reaches the lowermost edge of the operculum, after which the operculum is removed by twisting from its point of articulation with the skull; the operculum is then soaked for a short time in cold water and following this treated with boiling water for about five minutes. After boiling, opercula are cleaned with tissues and placed in envelopes for further examination.

Age determination was carried out by examining the opercular bones using a stereomicroscope. Le Cren (1947) describes the basis of the method as follows: on the opecular bone, opaque zones correspond to the rapid growth of the summer, and each of these gradually fades into a narrow transparent winter zone, which ends relatively abruptly, with a sharp line of discontinuity between it and the next summer zone. This sharp line marking the end of the winter band was always taken as the end of the year's growth.

Care had to be taken in examination in order to avoid counting false rings. True annual rings are characterized by a gradual change from opacity to transparency and end abruptly at the beginning of another opaque zone. False rings are common in the middle of the summer's growth and can be distinguished by their abrupt change from an opaque zone to a thin transparent band followed again by an opaque zone (Le Cren, 1947). The following terminology was adopted for describing the opercula: no ring (O), one ring (one-year-old), two rings (two-year-old) and so on. In arranging fish with view to growth studies the first of June was taken as the theoretical date of hatching as proposed by Le Cren (1958).

IV.2.4 **Data analyses**

Growth in length: mean total length was plotted against age to establish the growth curve. Then, the seasonal pattern of growth was investigated by plotting the mean total length per month.

Growth in length was also expressed in terms of the instantaneous growth rate in length (G_L) according to the equation

$G_L = \log_e \bar{l}_2 - \log_e \bar{l}_1$ (Ricker, 1975), where

$\bar{l}_1$ = mean total length at age x

$\bar{l}_2$ = mean total length at age x+1

Investigations were carried out in order to find if the perch population of Cobbinshaw Reservoir follow a growth curve of the von Bertalanffy (1938) type. The parameters were calculated according to the von Bertalanffy equation.

$l_t = L\infty[1 - e^{-k(t-t_o)}]$ in which

lt = lenght at time t.

L∞= the mathematical asymptote of the curve which refers to the 'final' or maximum size.

k = the rate at which the growth curve approaches the asymptote.

t_o = theorical age at which t=0

Growth in weight: mean total weight was plotted against age to establish the growth curve. Influence of gonad weight on total weight was investigated by comparing the growth using the total weight data with that using the somatic weight data. Influence of gonad weight on seasonal pattern of growth was also investigated.

The instantaneous growth rate in weight (G_W) was calculated according to the equation.

$$G_W = \text{Loge}\ \overline{W}_2 - \text{loge}\ \overline{W}_1 \quad \text{(Ricker,1975)}$$

in which

$\overline{w}_1$ = mean total weight at age x

$\overline{w}_2$ = mean total weight at age x+1.

Length-weight relationship: two methods were used to establish the length-weight relationship. The first one was the condition factor K, calculated for each age according to Fulton's equation:

$$K = \frac{W}{L^3} \times 100 \text{ where}$$

W= total weight

L= total length

The condition factor K gives the relation between weight and length and as proposed by Weatherley & Rogers (1978) the change in fish corpulence during life.

Although, the calculation of K is widely used in fishery research it is criticized due to some limitations. Nevertheless, it is of great value in comparing two populations of the same species living in different environments, in determining timing and duration of breeding cycles and for following changes in populations due to feeding alterations (Weatherley,1972; Weatherley & Rogers,1978).

The length-weight relationship was also investigated according to the equation $W=al^{b}$ (Bagenal & Tesch, 1978) in which W=fish weight, l=fish length. The following equation shows the logarithmic relation.

$$\log W = \log a + b \log l$$

A regression line of the graph log weight against log length gave b the regression coefficient which usually varies between 2 and 4, and a which is the intercept of the line on the y-axis (Bagenal & Tesch, 1978).

Most of the calculations were carried out using the statistical package SPSS (Nie et al., 1970).

Data were processed in the 2972 computer of the Edinburgh Regional Computer Centre (ERCC).

IV.3 Results and Discussion

IV.3.1 Comments on fish sampling

1310 perch were collected during the period of field work.

Traps proved to be successful for perch over four-years-old from May to July, but no fish were caught by this method from September to March. No trout or pike were caught in the traps.

Both seine nets used were effective for capturing perch (including fry), pike and trout. Their effectiveness, however, was somewhat lower from October to March. Although seining was very laborious and sometimes unsuccessful the majority of the perch were captured by this method. The single mesh-size gill-net was very selective and captured only pike and trout over 45cm while the gill-net with different mesh sizes provided a large range of size-classes, and seemed to be more suitable for the present work. Unfortunately, the latter net was used only a few times and therefore more information on its performance is not available.

Perch angling gave the highest catches in the summer but provided few specimens for this work, as many anglers kill the fishes and throw them away before returning to the clubhouse.

Table IV.1a,b shows the age-class distribution per sex of the fish collected by seine-net and traps in 1981 and 1982. Netting provided fish of different age- classes and shows no age-class selectivity.

Although the seine-net caught more males than females (Table IV.1a,b) this may be due to the presence of larger numbers of males in the population rather than to any sexual selectivity of the method of capture.

Trapping was very selective for size and provided mainly perch over four-years-old (Table IV.1a,b). Low catches of eight-and nine-year-old fish with both traps and seine nets are presumably due to the small numbers of these age-classes in the population.

It was observed that in 1981 the proportions of total captured males and females was more or less the same (Table VI.1a). In 1982 there was a predominance of females (Table IV.1b). However, catches analysed separately showed some seasonal trends in differential sexual capture.

Table IV.1 - Age class and sex distribution of the perch collected with seine-net and trap

a) 1981

AGE	SEINE NET				TRAP			
(YEARS)	MALE	FEMALE	UNDET.	TOTAL	MALE	FEMALE	UNDET.	TOTAL
0	3	0	48	51	1	0	2	3
I	27	29	4	60	0	2	0	2
II	3	5	0	8	0	2	0	2
III	22	4	0	26	0	3	0	3
IV	86	40	0	126	19	22	0	41
V	14	16	0	30	32	21	0	53
VI	36	36	0	72	43	38	0	81
VII	17	19	0	36	15	21	0	36
VIII	2	3	0	5	2	5	0	7
IX	0	1	0	1	1	3	0	4
TOTAL	210	153	52	415	113	117	2	232

b) 1982

AGE	SEINE NET				TRAP			
(YEARS)	MALE	FEMALE	UNDET.	TOTAL	MALE	FEMALE	UNDET.	TOTAL
0	17	3	14	34	0	0	3	3
I	25	36	1	62	0	1	2	3
II	55	19	0	74	2	8	0	10
III	11	2	0	13	2	7	0	9
IV	29	8	0	37	5	20	0	25
V	21	2	0	23	49	48	0	97
VI	16	11	0	27	30	40	0	70
VII	10	9	0	19	4	12	0	16
VIII	3	4	0	7	6	4	0	10
IX	0	7	0	7	1	2	0	3
TOTAL	187	101	15	303	99	142	5	246

There is some information in the literature of different rates of capture of the sexes in perch.

Worthington (1950) reported that trapping selected one sex or the other. Craig (1974a) found that traps in Slapton Ley (England) during five weeks of spawning were highly selective for males. Following spawning they selected females and at other times of year there appeared to be little selection of either sex. The latter author (1975) stated that 'there is a marked seasonal variation in the catching power of perch which to a large extent can be attributed to the behaviour of the fish'.

Fig. IV.1 shows the variation in number of males caught in relation to females in each month. The number of males reached a peak dominance in April remaining more or less the same until June after which they decreased very quickly. Numbers of females, on the other hand, increased slowly from March to June after which they decreased. From March to May the number of males was larger than that of female, while, with the exception of July, the reverse was the case from June onwards.

Fig. IV.2 shows the number of perch caught in each month. The number of fish captured increased from the spring to the summer, suggesting that the success of fishing is related to water temperature. More evidence, however, is necessary to support this as many other factors are involved: it should be remembered that the results in Fig.IV.2 represent collections of fish from different areas, using different fishing methods and including captures during the spawning season. One interesting observation, however, was that the catch was greater under better weather conditions.

Stott (1970) working in a pond experiment found that the optimum catching temperature is around 10.5°C, which usually correspond to the mean temperature in the spawning season. He also found a negative correlation between the capture of perch and temperature over the range of 15-21°C. Craig (1974a) observed that perch-trapping in Slapton Ley showed an increasing number of fish from the winter to a peak in April and a rapid decline during the summer months

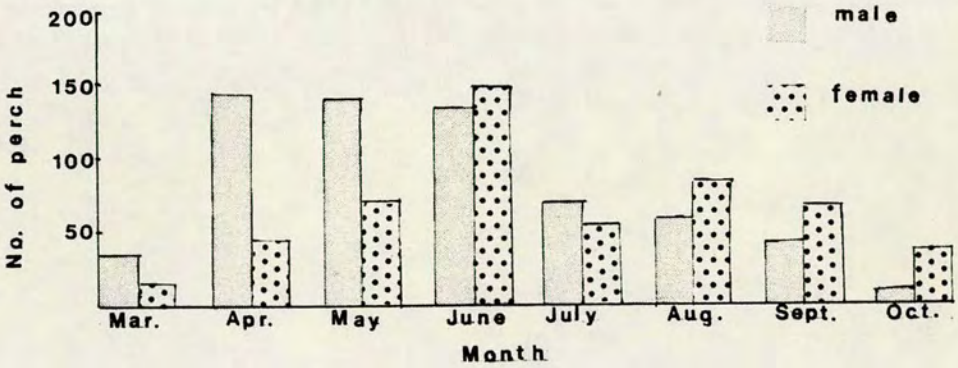


Fig. IV.1 - Monthly variation in the total number of male and female perch.

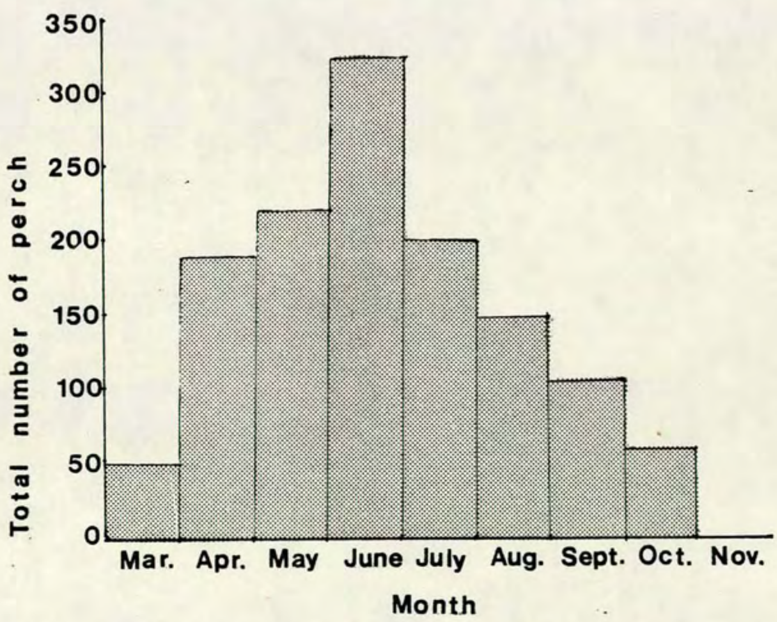


Fig. IV.2 - Monthly variation in the number of captured perch.

(May to August). He pointed out that trapping is not directly correlated with temperature and that spawning behaviour is one of the most important factors affecting perch-capture.

Le Cren et al. (1977) recorded in Windermere a predominance, sometimes exclusively, of males at the start of the spawning season, an increase of females from the middle of the season and a higher proportion of females at the end of the season. However, for the whole spawning season there were more males than females in the catch and the proportion of females varied from year to year. They suggested that females are vulnerable to capture for a shorter time than males.

Kammerer (1907) pointed out that intensification of colour in perch during the spawning season leads to aggregative behaviour, hence they are more liable to be caught by nets and traps in that period, which varies from water to water. Considerable information exists on the period of spawning in perch. Kukko & Lind (1972) observed the presence of males on the spawning grounds at Hildelampi, Finland, from 24 May to 14 June whereas females were only present from 2-9 June. Tsai & Gibson (1971) recorded spawning of yellow perch in the Patuxent River (Maryland) lasting only three days (13-15 May). Dryagin & Muratova (1948) recorded spawning from 8-10 May in the Cheboskar (River Volga); Jones (1982) observed spawning starting about 25 April and lasting four to five weeks in

Loch Leven (Scotland). Craig (1974a) recorded an eight-week period (from the second week of March to the first week of May) in Slapton Ley (England). My observations indicate that in Cobbinshaw Reservoir it lasts about seven weeks (from the second week of April to last week of May).

There was an improvement in the catch of fish in Cobbinshaw Reservoir during the spawning season which in turn coincided with an increase of water temperature to about 10°C. The numbers captured continued to increase until the end of the spawning season in June, after which there was a decline. However, the number caught remained fairly high in July and August when water temperatures were sometimes over 20°C.

It is quite clear that in Cobbinshaw Reservoir shoals of males move to shallow water for spawning before the females and probably spend far more time on the spawning ground. Thus, males are dominant from April to June (Fig.IV.1) at which time fishing was very intensive. Since trapping carried out to reduce the perch population is selective for fish over four-years-old (Table IV.1) it is possible that this is one of the main factors responsible for the mortality of older fish and particularly for reducing the number in the older age-classes of males in Cobbinshaw Reservoir, as discussed in the next section.

IV.3.2 Population Structure

Table IV.2 shows the male:female ratio of each age group of perch sexed during this work.

The total showed a predominance of males (644 individuals) over females (532 individuals) with a sex ratio of approximately 1:1. Nevertheless, differences were observed in each age group, as follows. Fish under one-year-old showed a sex ratio of 7:1 in an admittedly small sample (24 individuals). However, it was quite difficult to sex fish at this age and a large number of individuals of undetermined sex were recorded. The ratio male: female was more or less unity at one-year-old (1.05:1.16) while there was a predominance of males from two-year-old (1.60:1.00) to five-year-old (1.32:1.00). After seven-year-old there was a predominance of females (Table IV,.2) suggesting that longevity of the male is inferior to that of the female. Such differences in sex-ratio have been reported in other waters (Eschmeyer 1937,1938; Hile & Jobes, 1942; Carlander, 1950).

Table IV.2 - Sex ratio of total perch captured and sexed in each age-group

AGE GROUP	SEX-COMBINED No.	(%)	NUMBER OF MALES	NUMBER OF FEMALES	SEX RATIO
0	24	2.04	21	3	7.00:1.00
I	130	11.05	60	70	1.05:1.16
II	107	9.10	66	41	1.60:1.00
III	53	4.51	36	17	2.17:1.00
IV	232	19.73	142	90	1.57:1.00
V	207	17.60	118	89	1.32:1.00
VI	264	22.45	136	128	1.06:1.00
VII	113	9.61	49	64	1.00:1.30
VIII	31	2.64	14	17	1.00:1.21
IX	15	1.27	2	13	1.00:6.50
TOTAL	1176	100	644	532	1.21:1.00

There is no record of physiological mortality differences between male and female perch (Thorpe 1977b) which could be used to explain such results. Alm (1952) and Hölčik (1969) suggested that the effect could be a consequence of the presence of a large number of males and to their great activity which exposes them more to predation.

According to Table IV.2, the oldest perch captured was nine-years-old and this age class was represented by only a few individuals. Although longevity of this level is normal in perch populations, older fish have been recorded in others waters, e.g., 13-years-old in the Vistula River (Backiel,1971); 18-years-old in Mseno Reservoir (Vostradovsky 1962), 28-years-old in ponds in Sweden (Alm, 1952), etc. Many factors are related to such variation, however, Craig (1974a) suggested that 'longevity is best described on the basis of nutrition and growth rather than chronological age', and Brody (1945) proposed that fish longevity can apparently be correlated directly with the rate of growth.

IV.3.3 **Age structure**

Figure IV.3 shows the age frequency distribution of total perch captured in 1981 and 1982. It reveals an apparently atypical population with different age group and year-class strenghts.

In 1981 there was a predominance of the 1977 year-class and it was still the strongest group in 1982. The 1975 year-class was the second dominant group in 1981 but was a weak year-class in 1982.The third strongest year-class in 1981 was the 1980 year-class and it was still in the same position in 1982. An unexpected change occurred in the 1976 year-class, which was the fourth strongest group in 1981 but became the second in 1982. The 1979 year-class represents the weakest in both years 1981 and 1982.

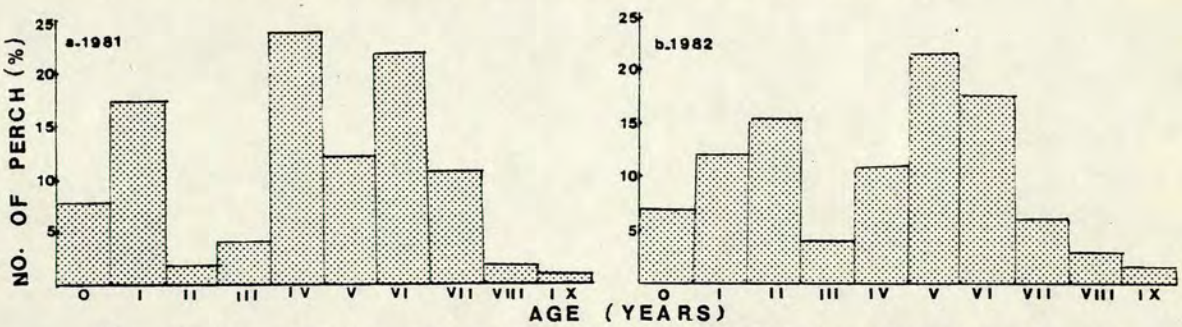


Fig. IV.3 - Age frequency distribution of total captured perch in 1981 and 1982.

Such variation in age groups and year-class-strength in perch is described by Burrough & Kennedy (1978a,b) as a characteristic of populations of this species.

Thorpe (1977b) pointed out that perch show a strong year-to-year variation in year-class strength which produces a wide variety in the age composition of the population in different waters. He considered it difficult to account for the varying success of different age groups as this depends on a complex of environmental factors and their effects on reproduction and recruitment. Furthermore, sampling methods can give an erroneous picture of age composition of populations since perch shoals frequently consist of a single age-and size-class.

Alm (1952) suggested that such marked variation in year-class strength, and consequently in the age-group composition, is more probably due to fry survival than to actual spawning success. Le Cren (1955) pointed out that in Windermere variation in age-group composition could be caused by climatic factors and Neuman (1976) similarly reported that in the Baltic Archipelago it was affected by water temperature. On the other hand Sumari (1971) found that in ponds in Finland differential predation was the answer to the variation.

Thus the factors affecting year-class strength and age groups composition are complex and difficult to account for at Cobbinshaw and elsewhere.

Furthermore, the lack of information on Cobbinshaw Reservoir's past environmental conditions and absence of records of perch and pike fishing from 1975 to 1978 (Appendix 1) make explanations even more difficult.

Another factor of importance is the adoption of a new trout stocking programme from 1979 onwards which has led to large increases in trout numbers. Since predation by trout is a cause of mortality of under one-year and one-year-old perch in Cobbinshaw it is possible that the advent of the new stocking programme also contributed to the establishment of the age composition observed in Fig. IV.3.

Craig (1974 a) reported that the spawning behaviour of perch affected their capture. Hence, presumably the recorded age composition was also affected by fishing methods used during this study. In fact, it was observed that the age composition of fish collected with the seine net was slightly different from those captured by trapping (Fig. IV.4).

Figure IV.4 shows that trapping demonstrates the strength of the 1975, 76 and 77 year-classes which I regard as dominant in the lake. Probably the most accurate representation of age-and size-classes in the population can be derived by combining the results from both seine-netting and trapping (see Fig.IV.3).

Probably, replacement and even an increase in the population is occurring very quickly due the predominance of fish at a possibly optimum spawning age (four-five-and six-year-old). The capture of 6110 perch in 1983 supports the idea that the population may be increasing despite intensive fishing.

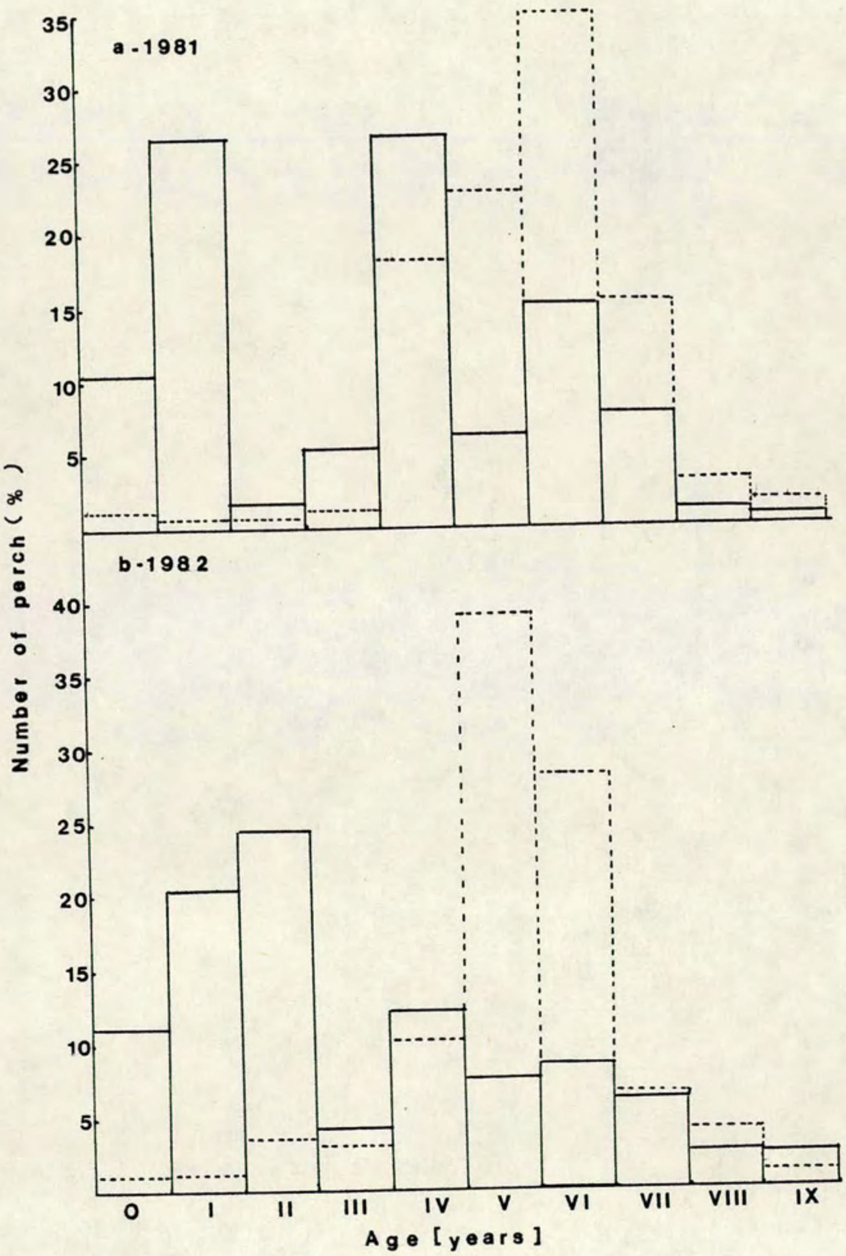


Fig. IV.4 - Comparison of the age composition of perch captured with a seine net (———) and those captured with a trap. (-----)

Nikolsky (1978) pointed out that absence of fishing might lead to an increase in the percentage of older individuals. Conversely, if fishing removes older individuals it could cause a rejuvenation of the population and acceleration of the growth and maturity of younger fish. Such aspects are discussed in the next section.

IV.3.4 **Length frequency analysis**

Figure IV.5 illustrates the length-class frequency and range of length in each age group for the total number of perch captured during the investigation. The dominant length-class ranged from 20 to 23cm, which includes fish from three to nine-years-old.

There is no common standard between different waters in the length distribution of perch populations. In fact, this character is very variable and is strongly affected by gear selectivity, sex distribution within populations and characteristics of shoals.

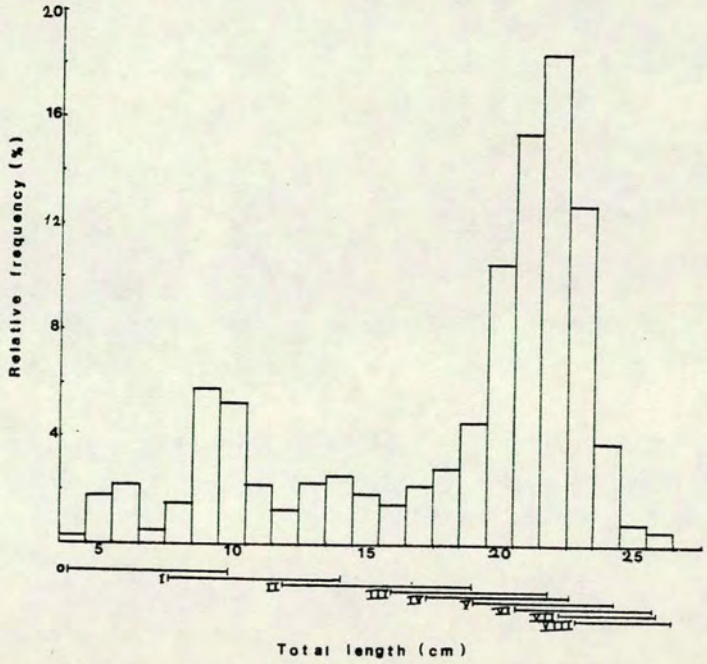


Fig. IV.5 - Length frequency distribution of total perch captured.

As shown in figure IV.5 distribution of length is normal and there is an overlap of lengths between different year-classes: this is most evident between three-and nine-year-old. Such size-variation in year-classes may be of great importance of reducing intraclass competition, as it means that the smallest and largest individuals may be exploiting different food-sources.

IV.3.5 **Growth in Length**

Figure IV.6 shows the growth curve in terms of length from Cobbinshaw Reservoir perch. Very fast growth occurred until the fourth year after which it became slower. Plate 2 shows perch of different ages from Cobbinshaw Reservoir.

Tesch (1955) classified the growth of perch into five types: A-(very good growth)-fish at age two years greater than 20cm total length, B-(good)-fish at age three greater than 20cm, C-(moderate)-fish at age three greater than 16cm, D-(poor)-fish at age three less than 16cm and E-(very poor) all fish less than 16cm of total length. In Cobbinshaw Reservoir the total lengths of many three-years-old fish were over 20cm, which means that their growth is of Tesch's type B (good).

Tesch also proposed a standard growth corresponding to his growth-rate classification. Figure IV.7 shows the growth curve in terms of length of perch from Cobbinshaw Reservoir compared with other waters. Growth curve of Cobbinshaw

Reservoir perch compares closely until age four with the standard proposed by Tesch (1955) and it is fast, at least until this age, when compared with the other waters plotted on the same figure.

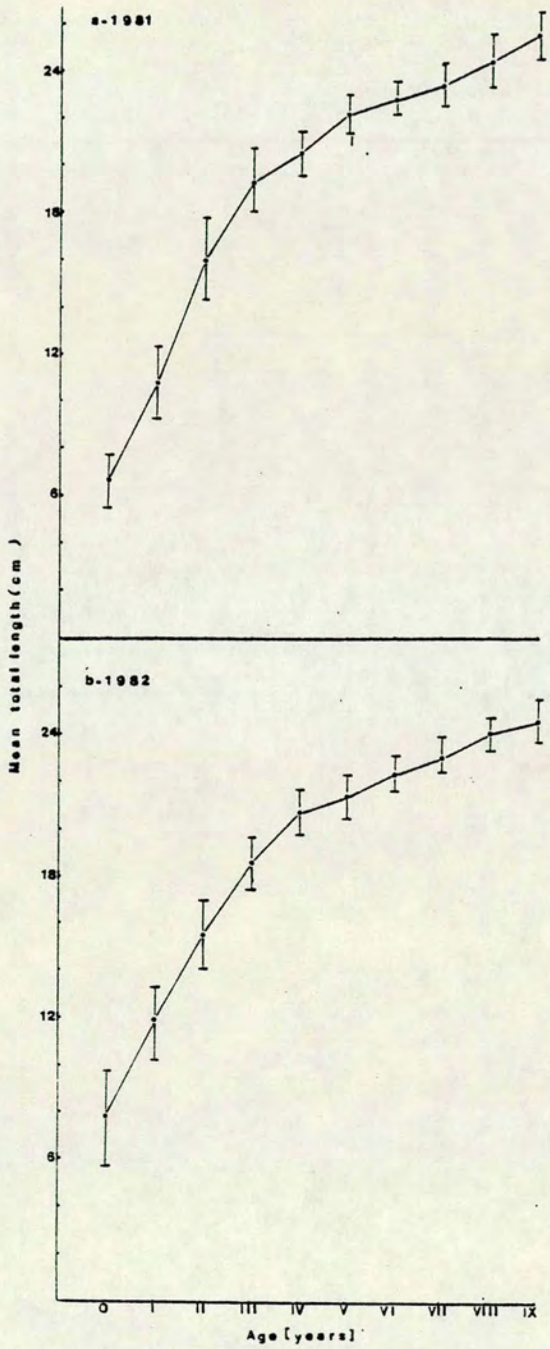
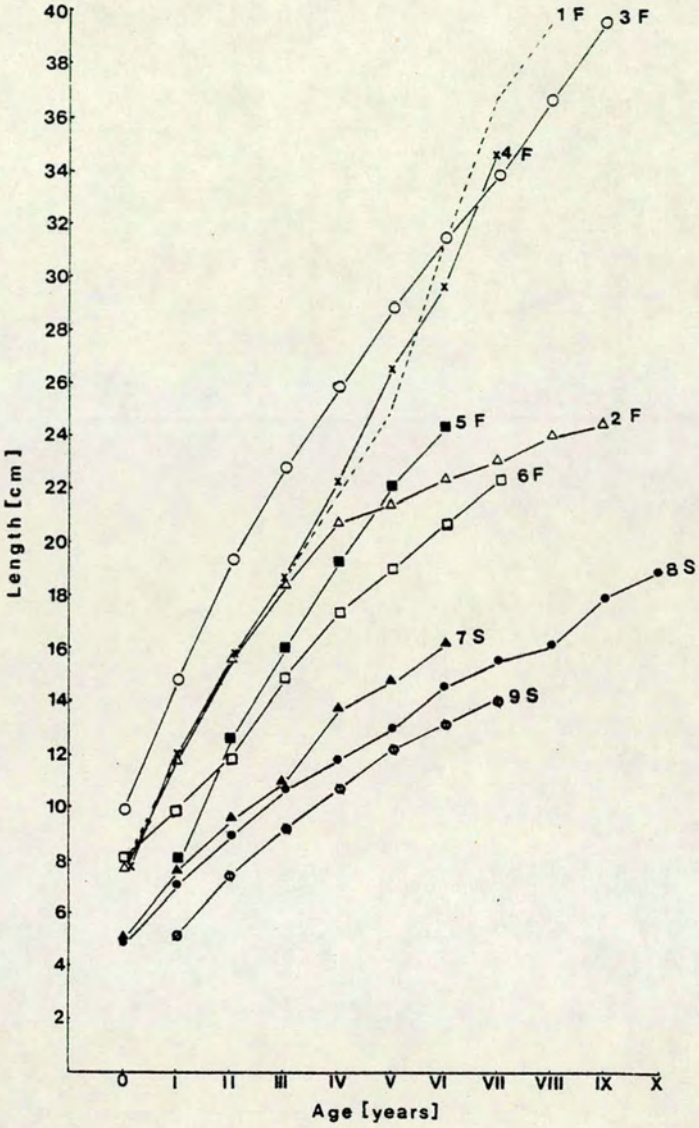


Fig. IV.6 - Growth curve in length of Cobbinshaw Reservoir perch. Bars represent 95%C.L.



1 "Standard growth" (Tesch, 1955)
2. Cobbinshaw Reservoir (1982)
3. Lake Chany (♀) (Tyurin, 1935)
4. Bondensee (Haakh, 1929)
5. Slapton Ley (♀) (Craig, 1974b)
6. Malham Tarn (Burrough & Kennedy, 1978a)
7. Windermere (♂) (Le Cren, 1958)
8. Loch Lomond (♀) (Shafi & Maitland, 1971)
9. Dubh Lochan (♀) (")

F = fast S = slow

Fig. IV.7 - Comparison between the growth of Cobbinshaw Reservoir perch and that of other waters.

The fastest growth of perch recorded that I have found was that noted by Weatherley (1967) in ponds at Narrandera, Australia (35.3cm in 22 months) and those of the Bodensee (Haakh, 1929) and Lake Chany (Tyurin, 1935) (Fig.IV.7). Growth of Cobbinshaw perch shows a similar pattern to that of the Bodensee perch up to three-years-old. Then, it becomes slower and shows a different pattern to all those shown in Figure IV.7.

The fast growth observed in the early stages of perch development is considered by Le Cren (1958) as very important for the population, since faster growing individuals mature earlier than slow-growers.

Table IV.3 shows the number and mean total length of mature and immature perch captured in 1981 and 1982. Mature fish were not recorded among zero-year-olds. Some mature males and females were, however, observed at one-year-old, which represents early maturation when compared whith other waters. It seems that males generally complete maturation before females, since at two-years-old there were more mature than immature males, whereas there were more immature than mature females at this age (Table IV.3). At three-years-old all perch were mature.

Table IV.3 - Maturity of perch from Cobbinshaw Reservoir at ages zero, one and two.

AGE	MATURITY	MALE (%)	MALE MEAN LENGTH ±95%C.L.	FEMALE (%)	FEMALE MEAN LENGTH ±95%C.L.
0	MATURE	-	-	-	-
	IMMATURE	100	9.5 ±0.2	100	9.7 ±0.9
I	MATURE	15.0	11.7 ±0.8	2.9	11.7 ±4.1
	IMMATURE	85.0	10.8 ±0.4	97.1	11.7 ±0.3
II	MATURE	68.2	15.9 ±0.4	36.6	17.7 ±0.7
	IMMATURE	31.8	14.5 ±0.4	63.4	15.6 ±0.3

Some other workers record remarkably early maturity in perch. Tesch (1955) found mature males at one-year-old and females one to two years later, while Healy (1954) in Lough Barnagrow (Ireland), Shilenkova (1959) in Kazakhstan lakes and Lake (1959) in Australia reported female spawning at age one year. Craig (1974b) recorded that 85.7% of two-years-old females in Slayton Ley were sexually mature and he pointed out that this record represented an early age for perch maturation in Great Britain.

Alm (1953,1959) concluded that growth rate influenced maturation and that age of maturation was influenced by genetic factors. As shown in Fig.IV.3 at the same age the size of mature perch in Cobbinshaw Reservoir is slightly greater than that of immature, particularly at two-years-old. One could speculate that in this lake fast growth and earlier maturation represent a strategy of rapid replacement of individuals to compensate for losses by fishing and natural mortality. Indeed, although removal of perch to eliminate them from Cobbinshaw started in 1910 and has been maintained ever since, the recent catches (see Appendix 1) show the lake still contains a large population.

Figure IV.8 shows the growth of males and females in 1981 and 1982 and Table IV.4 and IV.5 shows values (with 95% C.L.) used to plot the graphs.

Table IV.4 - Mean total Length (cm) with 95% confidence limits (if n>2) of perch of different ages from Cobbinshaw Reservoir (1981). Range of values are shown in parentheses.

AGE	MALE	FEMALES	COMBINED (including undetermined)
O	9.2 ±0.6	-	6.6 ±0.3
	(8.3 -9.9)	-	(4.7 -9.9)
I	10.2 ±0.4	11.4 ±0.5	10.2 ±0.3
	(8.7 -13.5)	(8.2 -14.5)	(8.2 -14.5)
II	15.1 ±1.6	16.5 ±1.2	16.0 ±1.0
	(13.4 -17.3)	(14.9 -19.5)	(13.4 -19.5)
III	19.0 ±0.4	20.3 ±1.0	19.3 ±0.49
	(17.3 -21.1)	(18.0 -22.3)	(17.3 -22.3)
IV	20.2 ±0.1	21.1 ±0.2	20.5 ±0.1
	(17.9 -21.9)	(18.9 -23.1)	(17.9 -23.1)
V	21.8 ±0.1	11.6 ±0.2	22.2 ±0.1
	(20.0 -23.5)	(20.9 -24.1)	(20.0 -24.1)
VI	22.3 ±0.1	23.2 ±0.1	22.8 ±0.1
	(21.0 -24.5)	(22.1 -24.8)	(21.0 -24.8)
VII	23.2 ±0.3	23.5 ±0.2	23.4 ±0.2
	(21.2 -26.1)	(22.2 -24.7)	(21.1 -26.1)
VIII	23.3 ±0.3	24.9 ±0.7	24.4 ±0.6
	(22.9 -23.6)	(23.3 -26.4)	(22.9 -26.4)
IX	24.3	25.9 ±0.8	25.5 ±0.8
	(24.3)	(24.8 -26.7)	(24.3 -26.7)

Table IV.5 - Mean total length (cm) with 95% confidence limits (if n>2) of perch of different ages from Cobbinshaw Reservoir (1982). Range of values are shown in parentheses.

AGE	MALE	FEMALE	COMBINED (including undetermined)
0	9.6 ±0.2	9.7 ±0.9	7.8 ±0.6
	(8.8 -10.3)	(8.8 -10.4)	(4.4 -10.4)
I	11.6 ±0.6	11.9 ±0.5	11.8 ±0.3
	(8.5 -13.4)	(9.2 -14.7)	(8.5 -14.7)
II	15.4 ±0.3	16.0 ±0.52	15.6 ±0.2
	(12.5 -18.0)	(14.0 -19.2)	(12.5 -19.2)
III	17.9 ±0.3	19.5 ±0.64	18.6 ±0.4
	(16.5 -18.8)	(18.4 -21.3)	(16.5 -21.2)
IV	20.3 ±0.2	21.4 ±0.25	20.8 ±0.2
	(18.5 -22.3)	(20.3 -22.5)	(18.5 -22.5)
V	21.2 ±0.1	22.0 ±0.21	21.5 ±0.1
	(19.5 -24.0)	(19.8 -23.7)	(19.5 -24.0)
VI	22.1 ±0.1	22.8 ±0.2	22.4 ±0.1
	(20.4 -23.1)	(20.3 -24.5)	(20.3 -24.5)
VII	22.6 ±0.3	23.5 ±0.2	23.1 ±0.2
	(21.8 -23.5)	(22.0 -24.3)	(21.8 -24.3)
VIII	23.8 ±0.3	24.4 ±0.6	24.1 ±0.3
	(23.4 -24.8)	(23.5 -26.2)	(23.4 -26.2)
IX	24.4	24.7 ±0.6	24.6 ±0.6

The figure appears to show that at all ages growth of females was slightly faster than that of males, however, statistical analyses of mean differences between males and females in each age group show that this is not the case (t-test $p>.05$). It was observed that the fish of one-and two-year-old showed no significant differences in either cohort. Similar results were observed for fish at eight and nine years of age. However, from three-to seven-years-old there was a highly significant difference between mean length of each sex (t-test $p>0.05$).

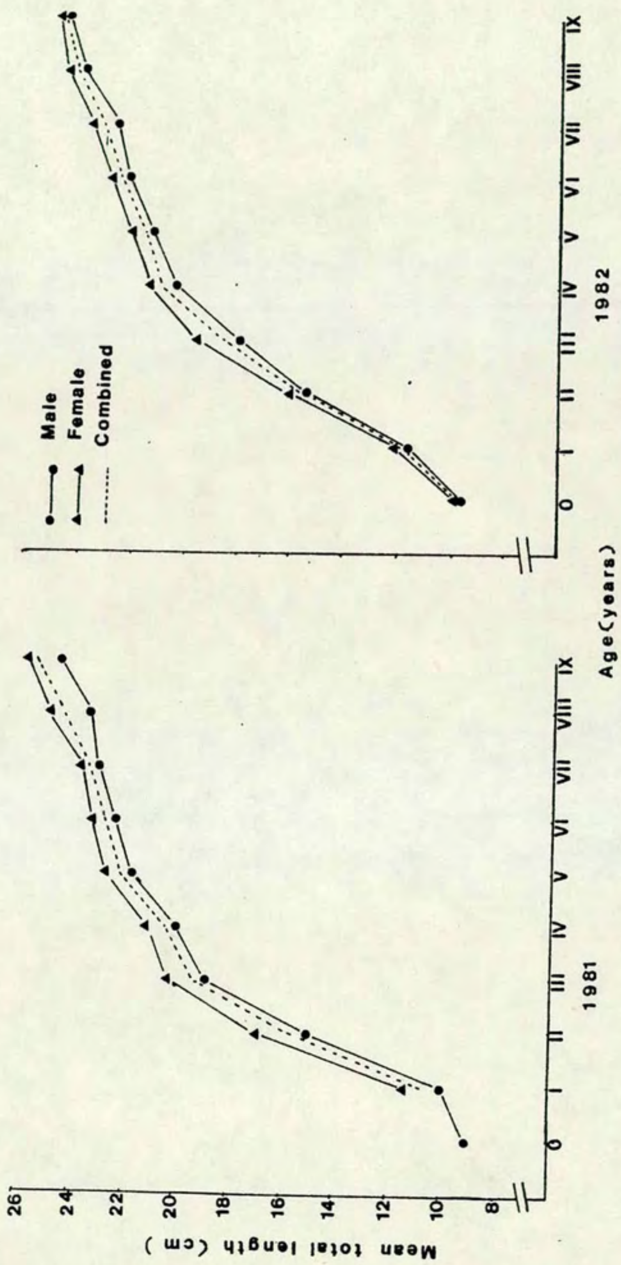


Fig. IV.8 - Mean total length (cm) of perch of different ages and sexes in 1981 and 1982.

Most of the published data agree that this observed pattern of growth of males and females is a common feature of nearly all perch populations. Le Cren (1958), for instance, noted no sex difference in growth during the first two years of life in Windermere. However, Scott & Crossman (1973) showed that in North America the yellow perch females grew faster than males from the first year onwards.

Many factors must be involved in determining the growth-rates observed in Cobbinshaw Reservoir perch. Apparently the most reasonable explanation is based on the assumptions for fish growth proposed by Nikolsky (1978), i.e., young fish use energy for linear growth and older (after onset of maturity) use it for ripening of the gonads, accumulation of fat and overwintering (if they do so).Thus, in Cobbinshaw Reservoir fish from zero-to three-years-old grew very quickly. After three years of age as they were sexually mature and presumably preparing for spawning in the very next season, growth became slower (Fig.IV.6).

Another aspect to be accounted for is the importance of fry density and food supply on growth of young. Although mortality of perch fry in Cobbinshaw Reservoir was not estimated, it is probably very high, since high mortality (sometimes up 99%) is expected for any fish population at this age (Alm, 1952). Since fry feed mainly on zooplankton which is widely and abundantly distributed in Cobbinshaw water it is possible that neither density nor shortage of food is affecting their growth. Thus, growth of young fish is fast. Older fish, on the other hand, feed mainly on bottom invertebrates which are restricted to the littoral area. At this stage interspecific competition with stocked trout and young pike could affect growth.

Another possibility is that fishing (particularly trapping) is imposing a heavy mortality on faster-growing older individuals and, consequently, giving more chance for slower-growing individuals.

A number of references show that separate growth-rate groups can occur within the same lake, which is a consequence of the perch's ability to occupy different niches as demonstrated by Ilina (1973). These different growth groups are probably related to different feeding habits. Schenerder (1908), Schiemenez (1919) and Roper (1936) distinguished three different growth groups according to the localities where the perch were feeding: (a) weed-bed, (b) open-water and (c) deep-water.Fishes feeding on invertebrates were considered as constituting a slower growth group by contrast than those that became piscivorous at an early age (Shentyakova, 1959). Cobbinshaw perch show a large size range in each age (Tables IV.4 and IV.5) which suggests the existence of such different growth groups. Data on the importance of perch feeding on growth-rate in Cobbinshaw Reservoir are presented in Chapter V.

Le Cren (1958) suggested that temperature is one of the most important factors affecting growth of adult perch due to its direct effect on physiology and to its indirect effect on food supply. He found a significant correlation between annual weight increment and the number of days from June to September with water temperatures above 14°C and suggested that year-to-year variation in growth can be largely attributed to temperature differences.

As shown in Figure II.6, temperatures over 14°C were recorded in Cobbinshaw Reservoir from May to September 1982. However, in May the average was only about 11°C due to the occurrence of cold days with temperatures of about 6°C. Such observations suggest that the best growth period was from June to September. This suggestion is confirmed by analysing the monthly pattern of growth shown in Fig.IV.9. Growth-rate was faster from June to August, the period in which the water temperature reached its highest value. Food supply also reached its peak at this time suggesting that a combination of food supply and water temperature are the main factors responsible for the higher growth-rate observed (i.e. the same conclusion as Le Cren, 1958).

However, although many authors considered temperature as a very important factor affecting growth-rate, Grimaldi & Leduco (1973) suggested that it is less important than other environmental factors such as pH and alkalinity in determining the growth of yellow perch in some Quebec waters. As discussed in chapter II, Cobbinshaw water is 'suitable' for perch growth, except for the alkalinity which showed low levels.

Figure IV.9 shows only the mean monthly variation of fish from zero-to four- years-old, as these groups represent the fastest growing group in the reservoir. With regard to the slower growth of fish over five-years-old, Neuman (1974) suggested that the growth-rate of fish becomes more sensitive to environmental variations as age increases and postulated metabolic factors which might be involved in this.

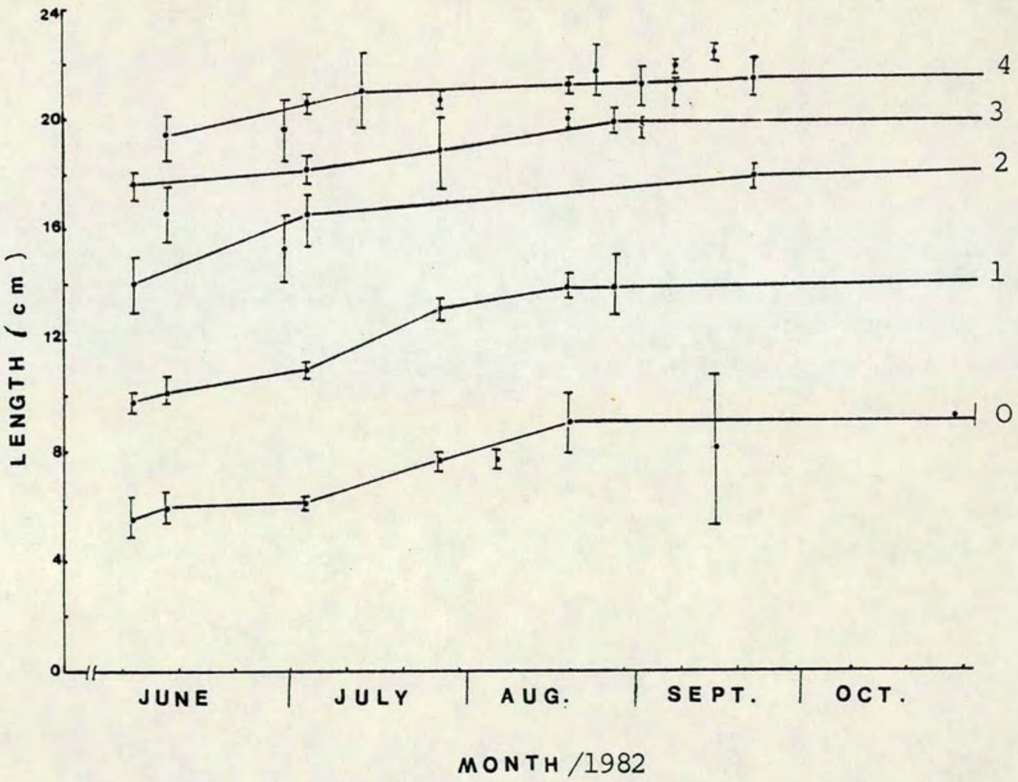


Fig. IV.9 - Plot of monthly mean lengths of different year-classes. Numbers (0,1,2,3,4) represent fish age

Another factor influencing growth-rate is population density. Le Cren (1958) demonstrated that a reduction in the total perch population of Lake Windermere had no effect on first and second year growth. His results agreed with observations of Alm (1946) working in pond experiments. However, the latter author found that growth after the third year was very slow and that growth in length was inversely related to abundance. Similar observations are also reported by Dymond (1926), Gchneberger (1935) and Eschmeyer (1937,1938).

Tesch (1955) pointed out that this inversely density-dependent growth is usually of short duration. He showed evidence that in the Sakrower See, East Germany, surviving perch showed an accelerated growth-rate after an almost complete kill of the fish populations. However, this phase did not last long because of the absence of predators and strong, new year-classes rapidly became established, after which there was a decline in growth. Parker (1958) working with yellow perch in Flora Lake, Wisconsin, also reported similar results.

Spangler et al. (1977) identified change in growth rate as one of the responses of percid populations to exploitation. They pointed out that very high growth rates are frequently observed in survivors of stocks which had almost collapsed due to intensive fishing.

Values of the von Bertalanffy growth model

Many researchers support the utilization of growth models as they facilitate comparisons between populations in time and space (Allen,1976) and give generalized descriptions of the pattern of growth (Dickie, 1978).

Attempts were made in the present investigation to discover if the growth of Cobbinshaw Reservoir perch follows the von Bertalanffy (1938) growth curve model.

To calculate the values of the von Bertalanffy equation $L_t = L_\infty[1 - e^{-k(t-t_0)}]$ the extrapolative Walford plot (Walford,1946) was used. Data from Tables IV.4 and IV.5 were used to plot the mean length of fish at age x+1 against the mean length of fish at age x (Fig.IV.10a,b,c,d). The value of L_∞ was obtained from the intercept of the regression line and the abscissa and K was given by -log slope of this line. The values of t_0 for each age were calculated from the following equation derived from the von Bertalanffy equation. The mean values of t_0 are shown in Table IV.6.

$$t_0 = [\log_e (1 - \frac{L_t}{L_\infty}) + Kt] \frac{1}{K} \qquad \text{(Guma'a,1978b)}$$

The fitted lines approached the diagonal of the graphs, at which length has reached its asymptote value, L_∞ (Fig.IV.10 a,b,c,d,). This indicates that the growth rate is regularly decreasing and that the growth of perch from Cobbinshaw Reservoir in fact follows the von Bertalanffy model. A similar result was also obtained from Windermere by Craig (1980) while contrasting results came from other works (e.g. Le Cren,1958; Hare,1965; Hart & Pitcher,1973; Mann,1978, and Guma'a,1978b).

Table IV.6 shows the values of the parameters of the linear regression and values of L_∞ and K obtained for perch in Cobbinshaw Reservoir, and Table IV.7 shows these values for different waters.

In 1981 and 1982 in Cobbinshaw Reservoir values of L_∞ were slightly higher for males than for females. The higher values I have found for L_∞ in perch from the literature were those observed by Thorpe (1977b) in Loch Leven and by Craig (1980) in Windermere (Table IV.6).

The values of K in Cobbinshaw Reservoir were higher for females than for males. With the exception for those of females in 1982 , these values were low (TableIV.6) when compared with most of those calculated by Craig (1980) for a period covering 17 years in Windermere (Table IV.7). However, the latter author also recorded some values lower than those obtained in Cobbinshaw Reservoir.

By comparing the value of L_∞ and K obtained in different waters (Table IV.7) it was observed that there are remarkable differences from water to water and between sexes and years in the same water. Such differences are attributed by Craig (1980) as being due to seasonal and annual changes in the environmental conditions (food supply, water temperature, light, etc.). Indeed, perch are considered as being very sensitive to variations of short duration in their environment (Frost & Kipling, 1967).

Table IV.6 - Results of the linear regression for the relationship between total length at x+1 and total length at age x for the perch population of Cobbinshaw Reservoir and values of L_∞ , K and to ± 95%C.L.

		REGRESSION PARAMETERS			von BERTALANFFY PARAMETERS		
YEAR	SEX	a	b	r	L_∞	K	to ± 95%C.L.
1981	MALE	5.17	0.81	0.96	27.0	0.21	-2.14±0.35
1981	FEMALE	9.15	0.64	0.98	25.6	0.45	0.24±0.41
1982	MALE	4.85	0.82	0.99	27.0	0.20	-2.33±0.18
1982	FEMALE	5.67	0.79	0.97	26.6	0.23	-2.42±0.27

Table IV.7 - Values of L_∞ , K and t_0 for different waters

METHOD	YEAR	LOCATION	SEX	L_∞	K	t_0	AUTHORITY
Bayley	1955	Windermere	M	23.38	0.27	-0.65	Craig (1980)
Bayley	1955	Windermere	F	26.30	0.26	-0.43	Craig (1980)
Walford plot	1955	Windermere	M	23.14	0.30	-0.59	Craig (1980)
Walford plot	1955	Windermere	F	25.53	0.31	-0.34	Craig (1980)
Walford plot	1963-1970	Slapton Ley	M	22.00	-	-	Craig (1974)
Walford plot	1963-1970	Slapton Ley	F	25.00	-	-	Craig (1974)
- -	1968-1973	Loch Leven	-	32.20	-	-	Thorpe (1977b)
Walford plot	1971	Windermere	M	26.60	0.44	0.11	Craig (1980)
Walford plot	1971	Windermere	F	30.58	0.34	0.06	Craig (1980)
Bayley	1971	Windermere	M	27.05	0.42	0.11	Craig (1980)
Bayley	1971	Windermere	F	36.10	0.25	0.05	Craig (1980)
Walford plot	1976	Windermere	M	6.72	-0.074	36.4	Guma'a (1978)

The literature shows that in some cases the use of different methods to calculate the parameters of von Bertalanffy equation may lead to different results. Craig (1980), for example, found different values for L_∞ and K in the 1955 and other cohorts when he used the Walford plots (1946) and the Bayley (1977) methods (Table IV.7).

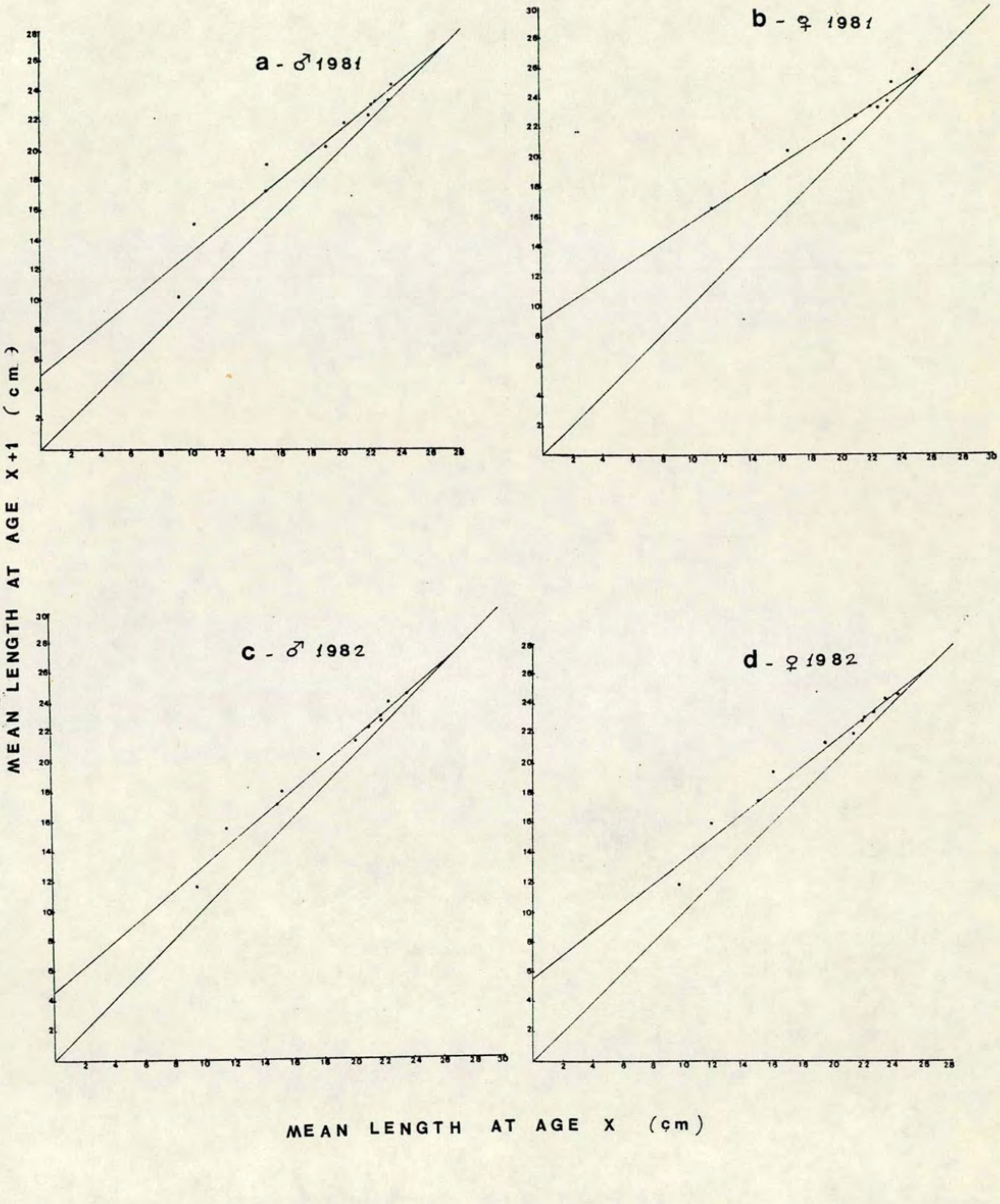


Fig. IV.10 - Walford plots for perch from Cobbinshaw Reservoir

Craig concluded that K values calculated by Walford plots (Walford,1946) are not always below those calculated by the Bayley method, and that only about half of the Walford values of K fell within the 99% C.L. of the Bayley K values.

No attempts have been made to compare values of K and L calculated using different methods as this was not the aim of the present work. However, more investigations are necessary to clarify this subject as Dickiel (1978) claim that the von Bertalanffy model is widely used in fish growth studies.

Ricker (1975) pointed out some sources of errors which could lead to bias in the interpretation of the Walford graphs. Among them are: (a) selection of larger size among young fish, which causes a depression of the left end of the line; (b) computation of age groups so affected; (c) reading scales of old fish consistently too low. Ricker (1975) commented on the von Bertalanffy model and criticized its utilization to explain fish growth on a 'theoretical physiological basis' as 'in nature fish are usually less fortunate' than the fundamental assumptions of the model. Nevertheless, he considered that growth curves from natural populations are close enough to the model to make it 'a useful empirical descriptive expression'.

Craig (1980) pointed out that curve fitting of the von Bertalanffy type is to a certain extent subjective. However, he suggested that such exercises are of value to show trends of each cohort and to smooth out irregularities.

The utilization of the von Bertalanffy model is even more uncertain for studies in environments like Cobbinshaw Reservoir, since the latter is a man-made lake in which the perch population is being strongly affected by intensive fishing, removal of spawn and presence of the introduced trout. Nevertheless, this model was used in the present work in order to provide information not available in the literature about the parameters for perch in an artificial environment.

IV.3.6 **Growth in weight**

There are some differences between growth in weight and length in fish. The latter is rapid and linear in its early stages and then becomes slow and eventually ceases with age; increase in weight, on the other hand, is a more irregular phenomenon since it is influenced throughout almost the whole life-span by factors such as the accumulation and use of fat reserves, increase and decrease of gonad weight, ingestion and elimination of food, etc. Nevertheless, graphs of weight-age resemble those of length-curves in usually being S-shaped, with the difference that in the former the point of inflexion is at an older age than in the latter.

Figure IV.11 shows the growth-curve in weight of the 1981 and 1982 cohorts of perch from Cobbinshaw Reservoir with both sexes combined. Differences in weight between each age-group are highly significant (t-test $p<.01$) with the exception of that between eight-and nine-years-old, where the difference is not significant even at $p > .05$. It is interesting in this context to note that Craig (1977) pointed out that in older perch these occurs at a higher expenditure of energy for gonad development and this is at the expense of somatic growth. This probably causes a reduction in the difference between weights of age groups of older fishes. However, the lack of significant differences in weight between these older groups could also be a consequence of the lower numbers of individuals sampled.

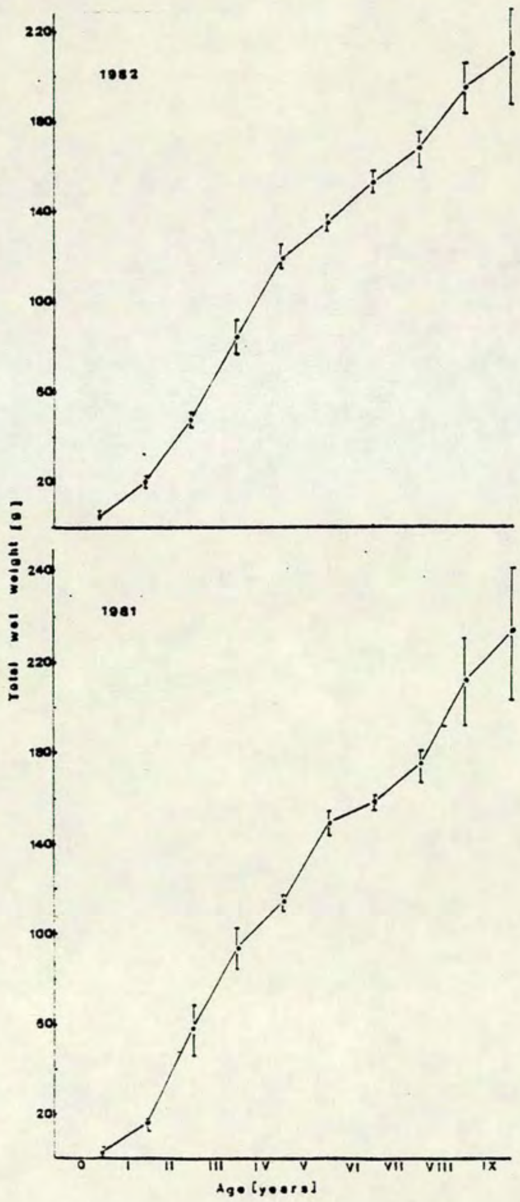


Fig. IV.11 - Weight growth-curve for perch from Cobbinshaw Reservoir. (both sexes combined). Bars represent 95 % CL

Table IV.8 shows the mean weight (with 95%C.L.) for males and females in 1981 and 1982 Mean weight of females was always higher than that of males in each age group. In 0-and one-year-old fish, however, such differences were non-significant ($p \leq .05$). At two-years-old and after the differences between females and males were significant in all age groups ($p \leq .05$). This is probably due to the fact that in female perch there is an increase of water content with ageing, whereas males show no such correlation at two-years-old and after (Craig,1977).

Table IV.8 - Total wet weight with 95%C.L. (if n>2) of perch from Cobbinshaw Reservoir in 1981 and 1982.

	1981		1982	
AGE	MALES	FEMALES	MALES	FEMALES
	Mean total weight ±95%C,.L	Mean total weight ±95%C.L	Mean total weight ±95%C.L	Mean total weight ±95%C.L
0	8.6 ±1.9	-	8.4 ±0.6	8.0 ±2.4
I	12.5 ±1.8	18.4 ±2.8	18.4 ±2.4	20.6 ±2.6
II	55.4 ±29.4	57.7 ±10.3	44.9 ±3.5	54.1 ±6.4
III	88.0 ±8.0	110.5 ±18.2	71.5 ±4.5	102.3 ±9.4
IV	105.2 ±3.2	126.1 ±4.6	106.6 ±6.3	136.3 ±5.9
V	136.5 ±4.0	163.6 ±4.3	128.1 ±4.0	144.3 ±4.9
VI	142.6 ±3.1	172.1 ±3.6	139.1 ±4.3	165.8 ±6.4
VII	164.9 ±10.4	181.5 ±7.8	149.5 ±8.5	179.0 ±7.3
VIII	176.5 ±11.2	229.5 ±18.7	183.8 ±7.1	207.0 ±18.5
IX	202.6 -	240.3 ±32.8	184.1 -	212.2 ±22.6

The maximum weight recorded was 290g in a nine-year-old female. This value is within the average maximum weight recorded in Scottish waters, although bigger fish have been recorded e.g. 900g in females from Loch Lomond (Shafi & Maitland,1971).

Figure IV.12 shows the weight growth-curve of perch from Cobbinshaw Reservoir in comparison with other waters. The data from the Bodensee (Haakh (1929) and Klicava (Hölčik, 1970) demonstrate very rapid growth in weight, much greater than Cobbinshaw, where, however, growth in length is very similar to the Bodensee. Nevertheless, Cobbinshaw apparently shows the highest rate at least for the first five years, of British waters (e.g., Loch Lomond (up to five years) and Dubh Lochan (Shafi & Maitland, 1971) and Windermere (Le Cren, 1958).

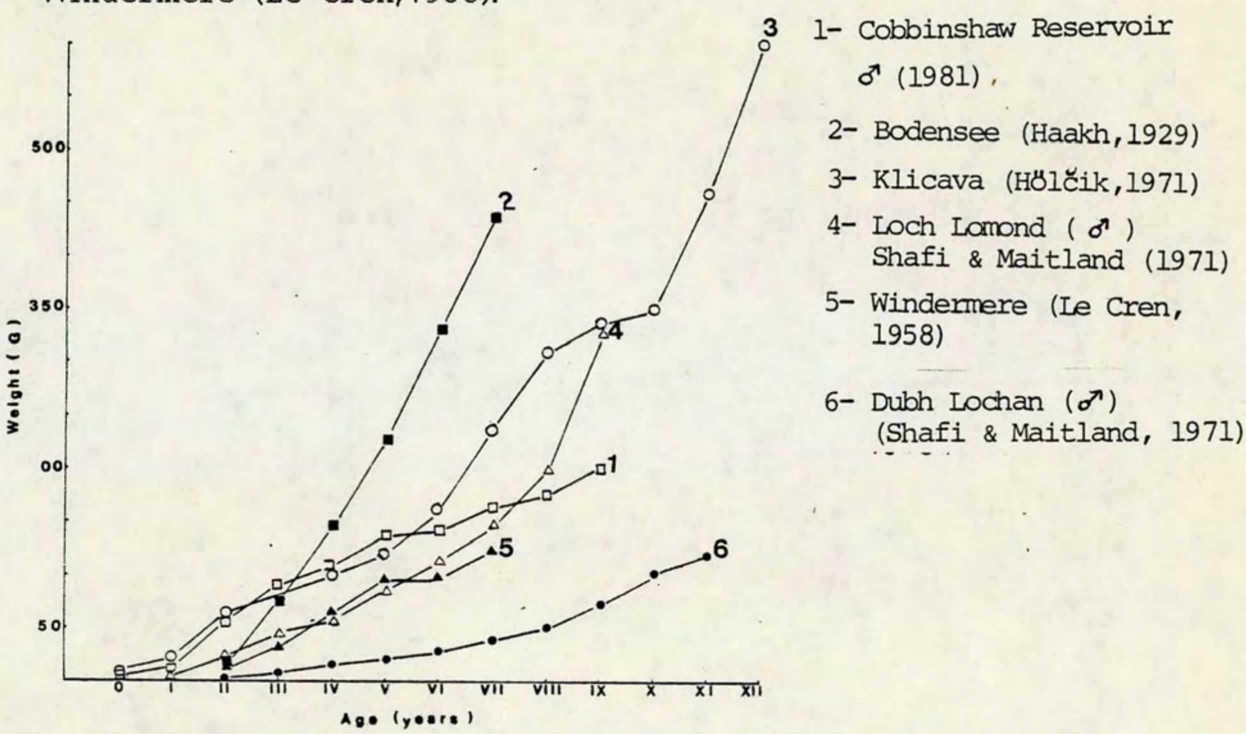


Fig. IV.12 - The weight growth-curves of perch from Cobbinshaw Reservoir and others waters.

A very important factor influencing variation in the weight of perch is the amount of fat, water and protein present in the soma and in the gonads, which shows seasonal trends

(Craig,1977). The last author showed that variation in body composition during the year in males is different to that of females. Morawa (1956) showed that perch accumulate fat in the body-cavity from May to October. Then the amount of fat decreases through the winter to reach a very low level in April.

Le Cren (1958) showed that in Windermere the ovary weight of mature perch reaches 23% of the body weight in April. In immature individuals, on the other hand, Le Cren (1951) recorded ovary weights about 0.5% of total body weight.

In Cobbinshaw, the gonad weight starts to increase in August and reaches a maximum value about April (before spawning). Plate 3 illustrates this situation.

In order to follow variation in gonad weight and its importance in total body weight, total weight, gonad weight, and somatic weight of four-year-old perch in 1981 were plotted monthly from April to September (Fig.IV.13).

In females the mean gonad weight decreases steadily during April (due to an increasing number of individuals having spawned) and this is accompanied by loss in total and in somatic weight. During the earlier part of May the gonad weight of females falls very sharply, probably associated with the end of peak spawning, and at the same time the somatic weight shows a sharp increase, although insufficient to compensate for the loss in gonads so that the total weight still actually decreases. The work of

Craig (1977) demonstrates the same effect, although in this case the somatic increase accompanied by gonad weight loss occurred in April. A probable explanation of the phenomenon is that by this stage in the spawning season all eggs in the ovaries are already mature, so no further energy expediture is needed for their development and the resources available from improved spring feeding can now be directed to recuperation in somatic weight.

In males gonad weight is much lower but there is still a great loss of total and somatic weight associated with spawning. The period of weight loss recorded for males is longer than for females-a situation which also occurred in the very comparable results of Craig (1977).

Following the weight losses associated with spawning body weight increased until September no doubt reflecting the higher temperatures and better feeding available. Obviously, such seasonal variation depends on fish maturity and only occurs in those of spawning age.

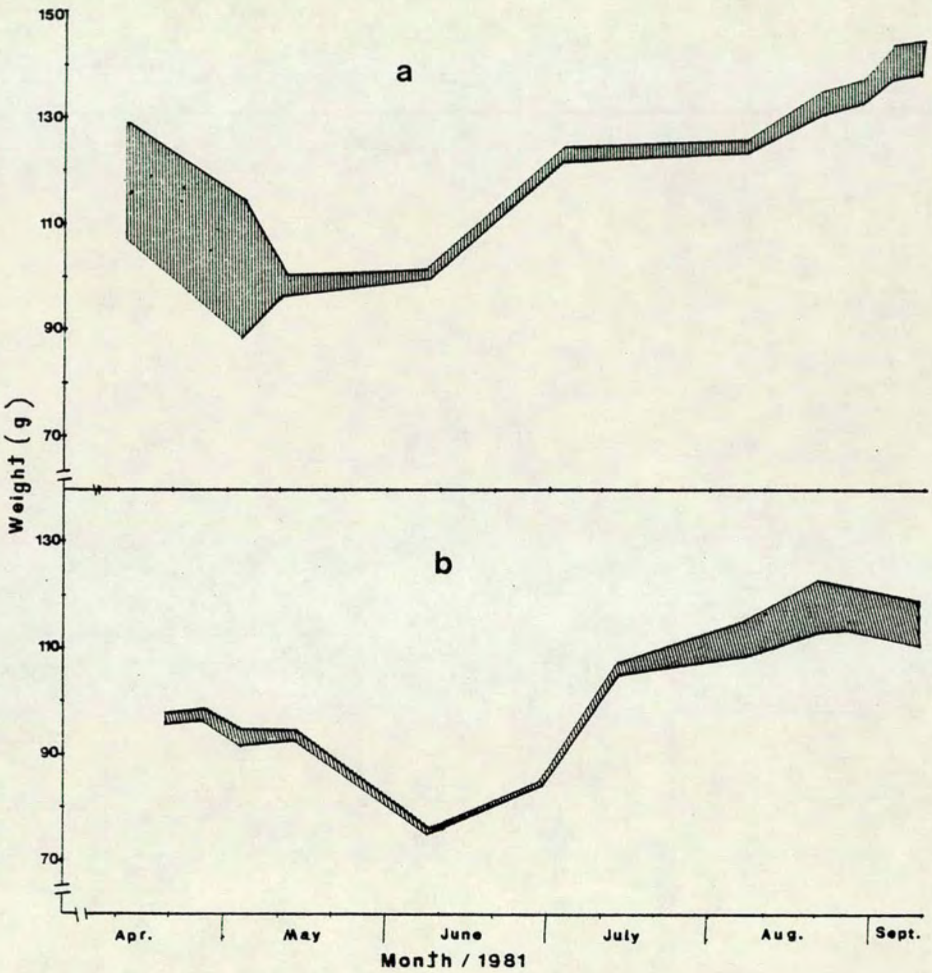


Fig. IV.13 - Monthly variation in mean weights of four-years-old perch from Cobbinshaw Reservoir in 1981. The solid black represents the gonad weight; the upper edge of the black represents total body weight and the lower edge the somatic weight. (a)females; (b)males.

Instantaneous growth

Table IV.9 shows values of instantaneous growth-rate in weight (G_W) between age groups. G_W is higher in the early stages of life, particularly between one-and two-year-old fish.

Table IV.9 - Instantaneous growth rate in weight (Gw) for perch from Cobbinshaw Reservoir in 1981 and 1982.

		AGES					
YEAR	SEXES	I	II	III	IV	V	VI
1981	MALES	1.49	0.46	0.18	0.26	0.04	0.14
	FEMALES	1.14	0.65	0.13	0.26	0.05	0.05
	COMBINED	1.31	0.49	0.19	0.27	0.05	0.10
1982	MALES	0.89	0.46	0.39	0.18	0.08	0.07
	FEMALES	0.96	0.64	0.29	0.06	0.14	0.08
	COMBINED	0.89	0.56	0.35	0.12	0.12	0.08

According to Vasnetsov (1953) early development of fish is characterized by the occurrence of distinct stanzas differentiated by abrupt changes in the structure and physiology; this causes a pattern of development with sudden changes in growth-rate and/or weight-length relationship.

Ricker (1975) proposed that although instantaneous growth-rate is more closely related to weight it could also be applied to length and that growth in weight and length are similar statistics differing only by a constant. From the logarithmic relation between weight and length ($\log w = \log a + b \log l$) he derived an equation to estimate instantaneous growth from length data: $G_L = b(\log_e l_2 - \log_e l_1)$ provided <u>b</u> is known.

In the present investigation the instantaneous growth in length (G_L) was estimated using another equation proposed by Ricker (1975): $G_L = \log e\ l_2 - \log e\ l_1$, where l_1=length at age x and l_2=length at age x+1. Results are shown in Table IV.10. As in the case of G_W, G_L is represented by higher values in the early stages.

Table IV.10 - Instantaneous growth rate in length (G_L) for perch from Cobbinshaw Reservoir in 1981 and 1982 cohorts.

		A G E S						
YEAR	SEXES	I	II	III	IV	V	VI	VII
1981	MALES	0.39	0.23	0.06	0.08	0.02	0.04	0.00
	FEMALES	0.40	0.20	0.04	0.07	0.03	0.01	0.05
	COMBINED	0.39	0.19	0.06	0.08	0.03	0.02	0.04
1982	MALES	0.28	0.15	0.12	0.04	0.04	0.02	0.05
	FEMALES	0.30	0.20	0.09	0.03	0.03	0.03	0.03
	COMBINED	0.28	0.17	0.11	0.03	0.04	0.03	0.04

Length-weight relationship

Studies on the length-weight relationship in this investigation were directed in two ways:(1)measurement of the divergence from the expected length/weight ratio to estimate condition, and (2)description of the mathematical relationship between length and weight.

The first aspect was studied by calculating the condition factor K according to Fulton's equation $K=w/l^3$, where w=total weight in grammes and l=total length in centimetres. The bigger the K value the better the fish condition.

Table IV. 11 shows the mean condition factor K for each age and sex in perch from Cobbinshaw Reservoir. The range varied from 0.79 in 0-year-old females to 2.68 in eight-year-old females. In both sexes, K values increased with age, with the exception of nine-year-old fish. Such results demonstrate that the condition of perch in Cobbinshaw Reservoir is good, particularly in older individuals.

Table IV.11 - Mean values of condition factor K with 95%C.L for different ages and sexes of perch from Cobbinshaw Reservoir (1982).

AGE (YEARS)	MALE	FEMALE	COMBINED
0	0.97+0.04	0.87+0.02	1.01+0.02
I	1.12+0.02	1.17+0.02	1.15+0.01
II	1.21+0.05	1.28+0.03	1.24+0.00
III	1.25+0.03	1.34+0.05	1.28+0.02
IV	1.27+0.01	1.36+0.02	1.30+0.01
V	1.33+0.02	1.37+0.01	1.35+0.01
VI	1.29+0.01	1.39+0.02	1.33+0.01
VII	1.31+0.02	1.39+0.02	1.36+0.02
VIII	1.37+0.04	1.45+0.04	1.41+0.03
IX	1.34+0.14	1.41+0.06	1.40+0.05

Lower values for condition observed in very young individuals are presumably related to the pattern of growth, which during the first three years is predominantly linear, and to the type of food. In this context Pycha & Smith (1955) observed that in yellow perch from Red Lake (Minnesota) there was no correlation in the same year between growth of fry and older year-classes. This was attributed to the habitat and food of fry being different from those of older fish. Le Cren (1951) pointed out that changes in the length-weight relationship from immature to mature perch are more closely correlated with the state of maturation than with age. Craig (1974a) showed that in perch from Slapton Ley the condition of mature females declined form April to May, correlated with spawning, whereas that of immature females increased very quickly in the same period. He also observed a sudden drop in the condition of females in August which was attributed to feeding behaviour rather than gonad development.

Changes in condition are also related to changes in body composition and season. Schneider (1973) found that small starved yellow perch contained more water than well-fed fish. Morawa (1956) showed that the amount of fat in the head and muscles of European Perch was very low in all seasons and that in the viscera it varies enormously during the year. He also discovered that females contain more fat than males. Such observations may explain why in Cobbinshaw Reservoir, as in many other lakes, the condition K of females is usually higher than that of males.

K values in other waters are shown in Table IV.12. Some of these values (e.g.2.73,3.94) represent the maxima found in the literature and are considerably higher than the mean obtained for perch from Cobbinshaw Reservoir. However, the values of the latter are higher than most of those recorded in other British waters. It is difficult to compare K from different waters because methods of measurement and analysis used vary widely. For instance, Lind et al.(1973) calculated K using W as the intact weight and also as the weight without gonads and the alimentary canal. Carlander (1950) used length in millimetres and weight in grammes while Chikhova (1973) used length in centimetres and it is therefore difficult to see how their results are comparable.

Table IV.12 - Values of condition factor K for perch from different waters.

SPECIES	LOCATION	K VALUES	AUTHORITY
<u>Perca flavescens</u>	America	1.10-3.94	Carlander(1950)
<u>Perca flavescens</u>	Klamatah River (California)	1.73	Coots(1956)
<u>Perca flavescens</u>	Oneida Lake	1.50-1.81	Hutchison(1974)
<u>Perca fluviatilis</u>	Windermere	0.76-0.98	Le Cren(1951)
<u>Perca fluviatilis</u>	Dubh Lochan	0.85-1.69	Shafi & Maitland(1970)
<u>Perca fluviatilis</u>	Loch Lomond	0.91-1.33	Shafi & Maitland(1970)
<u>Perca fluviatilis</u>	Lake Kintajarvi (Finland)	0.78-1.20	Lind et al(1973)
<u>Perca fluviatilis</u>	Kuybyshew Reservoir(USSR)	1.43-1.75	Chikhova(1973)
<u>Perca fluviatilis</u>	Volga Delta	2.04-2.73	Nikolsky(1978)
<u>Perca fluviatilis</u>	River Stour (England)	0.82-1.10	Mann(1978)

The mathematical length-weight relationship of perch from Cobbinshaw Reservoir was investigated by using the equation $\log w = \log a + b \log l$ (Ricker,1975). A regression analysis was carried out for both sexes in each year by plotting mean weight against mean length (logarithmic scale). Results are shown in Table IV.13. A very high correlation (r=0.99) was observed in all cases and values of <u>b</u> were always higher than three.

According to Ricker (1975) when <u>b</u> diverges from 3 the growth is described as allometric. Such observations were recorded for perch in other waters and Le Cren (1947) pointed out that the opercular bone of Windermere perch also shows allometric growth in relation to the length of the fish.

Table IV.13 - Data for regression of total weight on total length (logarithmic scales) for perch from Cobbinshaw Reservoir in 1981 and 1982.

YEAR	SEX	REGRESSION PARAMETERS			STANDARD ERROR
		INTERCEPT loga	SLOPE b	r	
1981	COMBINED (IMMATURE)	-2.098	3.155	0.99	0.036
1981	COMBINED (MATURE)	-2.186	3.230	0.99	0.037
1981	ONLY FEMALES	-2.160	3.219	0.99	0.033
1981	ONLY MALES	-2.107	3.163	0.99	0.036
1981	COMBINED (TOTAL)	-2.123	3.182	0.99	0.035
1982	COMBINED (IMMATURE)	-2.230	3.255	0.99	0.049
1982	COMBINED (MATURE)	-2.168	3.219	0.99	0.039
1982	ONLY FEMALES	-2.205	3.255	0.99	0.037
1982	ONLY MALES	-2.282	3.296	0.99	0.043
1982	COMBINED (TOTAL)	-2.260	3.288	0.99	0.042

Factors affecting fish weight and length already discussed are obviously related to variations in the value of a and b in the mathematical length:weight relationship.

Bagenal & Tesch (1978) showed that a and b coefficients may differ between species, between stocks of the same species, between stanzas and with major environmental changes. The coefficient a, on the other hand, often varies with season, time of day and between habitats.

Le Cren (1951) found in a study of a length-weight relationship that perch could be divided into six groups corresponding with age, sex and maturity:(1)larvae; (2)0 and one-year-olds; (3)immature females; (4)mature females; (5)immature males, and (6)mature males. Each group was homogeneous within itself throughout the season, but usually differed from the other groups. Variation between groups was attributed to seasonal variation in gonad weight and variation in stomach contents.

V. FOOD AND FEEDING HABITS OF PERCH AND TROUT AND THEIR FEEDING RELATIONSHIP

V.1 Introduction

The aim of this chapter is to describe the food and feeding habits of brown trout and perch from Cobbinshaw Reservoir and to establish if there is any kind of feeding interaction between these species. The investigation was concentrated on the pattern of seasonal composition, size and abundance of the main food-items used by both species and on the comparisons between the composition of food eaten by the fish and that available in the lake.

Every species of fish is structurally adapted to feeding on a particular food. However, the structures change during growth and development and, consequently, the composition of food within the same species may change with age. The food composition may also differ between the sexes. Such variation in the composition of the diet is a very important adaptation towards increasing the range of the food supply of a population. Furthermore, different kinds of food are required at different stages of growth thus reducing intraspecific competition.

According to Nikolsky (1978) the majority of fishes feed on plankton in the younger stages when orientation is by means of sight and the organs of the lateral line. However, some adults use tactile and taste organs to seek their food - the taste organs consist of numerous cells on the lips surrounding the mouth. Nikolsky also pointed out that predators and planktivores generally search for food by sight while benthophages use tactile and taste organs in their darker environment.

Much has been written on the feeding interrelationships of different species of fish in freshwater, particularly with regard to the Salmonidae. Examples of works on this subject are Leonard & Leonard (1949) in the United States; Nilsson (1955,1957) in Sweden; Hartley (1948) and Frost (1950) in England; Campbell (1955), Maitland (1965) and Thorpe (1974) in Scotland; Thomas (1962) in Wales; Moriarty (1963) and O'Grady (1983) in Ireland.

However, the subject is not completely understood and, as Hynes (1970) points out, the observations are sometimes only based on food organisms actually taken from the fish rather than an analysis of the whole habitat. In particular there are few works dealing with the subject of the present investigation, i.e the feeding interaction between perch and brown trout. In British and Irish waters, amongst those which exist are Campbell (1955) and Thorpe (1974) in Scotland, Burrough & Kennedy (1978a,b) in England and Moriarty (1963) in Ireland.

V.1.1 Previous studies on the food of trout and perch from Cobbinshaw Reservoir

Information on food and feeding habits of trout and perch from Cobbinshaw Reservoir are almost completely lacking. In fact, only two works mentioned such aspects. The first is the report of Steven & Cross (1949) who without adequate information stated that perch and trout from Cobbinshaw were competing for food (freshwater shrimps, snails and larvae of insects). The second work is that of Boyd (1975) who worked on perch from Cobbinshaw in November 1974. He observed that most of the fish captured had empty stomachs. However, in the few fish with food in their stomachs those under 10cm had eaten Copepoda, Cladocera and Chironomidae while those over 26cm had fed on _Gammarus pulex_, _Asellus aquaticus_, Diptera, Tipulidae (larvae), Oligochaeta and _Corixa_; unfortunately no data are given for fish between 10cm and 25 cm. Boyd also pointed out that despite the apparent abundance of Corixidae in the lake these organisms were scarce in perch stomachs and claimed that this observation agreed with the work of Cragg-Hine (1964) who stated that occurrence of corixids in perch stomach is not a common feature.

The work of Steven & Cross (1949) was based only on information of perch catches provided by the record book of Cobbinshaw Angling Association. Presumably he did not carry out any investigation on the food and feeding habits of perch and trout since no information on the subject is given in his report. Boyd (1975), on the other hand, fully realised that as his sample was very small and comprised only fish collected in two days in November, no definite conclusion could be drawn from his results.

V.1.2 **Food and feeding habits of perch**

The literature on perch food and feeding habits is very rich and shows that they vary enormously from water to water. Such observations permit one to classify the perch as euriphagic according to Nikolsky's (1978) classification,i.e., fish feeding on a variety of food.

In order to illustrate how the food of perch differs from water to water some results from the literature are summarized in the following paragraphs.

According to Alm (1922) in some Scandinavian waters small perch feed on the crustaceans of the plankton, middle sized ones on insect larvae and other bottom fauna, and the largest on small fish.

Allen (1935) found that, in Windermere, perch less than 14cm feed on plankton, those between 14 and 18cm on bottom fauna and those over 18cm on fishes.

Roper (1936) stated that in Germany one-summer perch feed on planktonic crustaceans, perch of two summers (up to 15cm) on insect larvae and those over 15cm on larger animals.

Healy (1954) discovered that almost all of the perch up to 26cm in Barnagrow Lake (Ireland), and those up to 24cm in Lough Glore (Ireland) fed on plankton. She also observed that in summer in Lough Glore all perch fed on Gammarus duebeni, Asellus aquaticus and chironomid larvae and pupae, although in May and June A.aquaticus seemed to be replaced by Odonata nymphs. Gasterosteus aculeatus was present in the 12-14cm perch. Chara vulgaris was found in 51 stomachs, Hirudineae in 80 and Mollusca in 32. In the winter the principal food was Asellus aquaticus, Gammarus duebeni and plants.

McCormack (1970) found that in Windermere a succession in feeding from plankton to benthos-to fish-feeding occurred as the perch increased in size. She found that Asellus was a very important food for perch and that perch of all size groups ate planktonic crustaceans and benthic fauna. She also observed that food intake varied from month to month, as did the numbers of different kinds of organisms eaten. 35% of all the perch stomachs examined in August were empty.

Craig (1974a), in Slapton Ley, found that perch below 9cm fed predominantly on plankton and chironomid larvae, above this and up to 13cm they used a wider range of organisms, while those of 14cm and above fed on fishes. Amongst the planktonic crustaceans eaten by large perch were Cyclops hyalinus (very common), Diaptomus gracilis, Daphnia sp, Cyclops abbidus and Chydorus sphaericus (frequent) and Ceriodaphnia sp (occasional). Ephemeroptera nymphs, predominantly Caenis moesta, were also recorded as an important food of perch. In the same work Craig (1974a) observe that one perch had its stomach full of Argulus spp, an unusual food-item. Chironomids, plankton and Asellus were very important food-items for large perch (especially during the winter months). He also found that abundance of food was more important in selection than its absolute size - in contrast to the observations of Healy (1954). He did not find clear divisions between planktonic, benthic and fish-eating perch as McCormack (1970) found in Windermere.

Thorpe (1974) observed that in Loch Leven (Scotland) Asellus was the most important food component by weight in the summer and cited other important food-items, viz: benthic and planktonic crustaceans (mainly Daphnia) perch-fry, chironomid larvae and leeches.

Hartmann (1974) in the Bodensee observed a change from benthos feeding in the winter to plankton feeding in the summer.

Craig (1978), in Windermere, found that seasonal changes in the diet of perch are the result of the availability of the prey as well as the consequence of activity and behaviour of the prey and of the predator. He also showed that in Windermere, with minor exceptions, perch fed on benthic organisms (including perch-fry) from November until April, on benthos and plankton during May and June, and on perch-fry and zooplankton from July to October. The last period was the main feeding time and included as principal food Daphnia hyalina, Lepdtodora kindti and Bythotrephes longimanus. Other organisms found were chironomid larvae and pupae, Sialis lutaria, Erpobdella octoculata, Asellus aquaticus, Gammarus pulex and Crangonyx pseudogracilis.

Guma'a (1978a), in Windermere, found that perch in the first summer of their life changed their diet considerably.

The smallest food organisms in the smallest perch were ciliates, algae (most numerous), rotifers and a small number of copepod nauplii. In larvae of perch between 7 and 20mm Bosmina obtusirostris, Cyclopoid Copepoda, Diaptomus gracilis, and Daphnia hyalina predominated. In August he found that the most abundant food was the Amphipod Crangonyx pseudogracilis. Benthic invertebrates were taken very early in life, particularly Chironomidae. Cannibalism was infrequent and occurred only in four juveniles (>40mm) taken between dusk and midnight. Occasionally Polyphemus pediculus, Caenis spp and other ephemeropteran nymphs and Argulus spp occurred in the diet.

Mann (1978), in the River Stour (England), found that ephemeropteran nymphs, minnow fry and Corixidae were the most numerous food in one-year-old perch, whereas older perch contained Corixidae and a wider range of fish species, including minnows).

Burrough & Kennedy (1978a), in Malham Tarn, found that in July 1977 many of the stomachs of perch were empty. The major food was caddis larvae and molluscs (Lymnea pereger and Pisidium spp.)

V.1.3 **Previous work on food and feeding habits of brown trout**

The brown trout, like the perch, shows a great diversity in its food preferences from water to water. Clearly it would be inappropriate to try to review the

There is an extensive literature on the feeding habits of the brown trout and some of the data most relevant to this study are considered in the following paragraphs.

Wheeler (1969) described the food of trout at different stages of growth. The fry eat the aquatic stages of Ephemeroptera, Coleoptera and Chironomidae. The parr include large amounts of winged insects, nymphs of both Ephemeroptera and Plecoptera, larvae of Coleoptera and larvae and pupae of Chironomidae in their food. Adults feed on fishes, Crustacea (particularly Gammarus), aquatic insect larvae and adult winged forms. In this context Mills (1971) described trout as very catholic feeders, cropping the bottom fauna and organisms which fall on the surface of the water.

The trout's food is extensively discussed by Frost & Brown (1972) who point out that this fish is essentially carnivorous, feeding mainly on aquatic organisms (Insecta, Mollusca and Crustacea) and on a few terrestrial ones. The aquatic invertebrates included in the diet are adult insects (Hemiptera, Coleoptera), insect larvae, pupae or nymphs (Ephemeroptera, Plecoptera, Neuroptera, Odonata, Diptera (mainly Simulium) and Chironomidae. Mollusca (Gastropoda and Lamellibranchiata); Crustacea (Asellus, Gammarus, Astacus, Cladocera, Copepoda and Mysis); Oligochaeta; Turbellaria and Hirudinea.

Among terrestrial organisms eaten by trout Frost & Brown (1972) cited insects (Diptera, Homoptera (Aphids) and Coleoptera) and others eaten at times of high water, particularly when rivers are in flood, such as earthworms, slugs, woodlice, spiders and even mice. Among fish eaten were: perch, sticklebacks, minnows, gudgeon, loach, bullheads, eels and young salmon. Cannibalism is also often mentioned in the literature.

Hartley (1948) investigating the food and feeding relationships in the River Cam (Cambridgeshire) and Shepreth Brook (Lake District-England) divided the fishes into four groups on the basis of their food. In this classification brown trout, together with eels, were included in the category of fish eating a variety of foods. Among the organisms eaten by trout he found Mammalia, Amphibia, Arachnida, Insecta (Ephemeroptera, Hemiptera, Trichoptera, Lepidoptera, Coleoptera, Hymenoptera, Diptera); Crustacea (with a predominance of Gammarus pulex and Annelida (Oligochaeta).

With regard to the diet of trout in lakes, Allen (1938) found that in Windermere the feeding habits are closely related to seasonal changes in the bottom fauna. Between October and February trout fed mainly on snails, Asellus and shrimps. In the spring they ate aquatic insects (Plecoptera, Trichoptera and chironomid). From May to July they preferred Trichoptera (Leptocerus and Limnephilus) and in November and December charr eggs were a very important constituent of the diet.

Frost & Smyly (1952) showed that in Three dubs Tarn - a moorland fishpond in the Lake District, England - brown trout changed their feeding habits through the year as follows: March (trichopteran larvae, ephemeropteran nymphs, Pisidium and a predominance of Sialis); April (mainly chironomid pupae); May (terrestrial and aquatic winged insects, chironomid pupae, weed, trichopteran larvae and Pisidium); June (winged insects - particularly terrestrials - leptocerid larvae, chironomid pupae, Caenis); July (leptocerid and chironomid larvae, chironomid pupae, nymphs of Caenis); August (trichopteran and chironomid larvae, chironomid pupae and winged Trichoptera); September (winged Diptera, aphids, mud-and weed-living organisms).

O'Grady (1983) investigated the dietary habits and feeding rates of wild and stocked trout in some Irish lakes. He concluded that Gammarus pulex, Asellus, Gastropoda, trichopteran larvae, zooplankton, Hemiptera and chironomid pupae were the dominant items in the stomachs of both wild and stocked fishes. He also found that recently introduced fish did not eat these invertebrates and some of them ate small stones and organic detritus.

V.1.4 Feeding relationship between brown trout and perch

In spite of the diversity of works on fish feeding interrelationships, the literature includes very few complete investigations devoted to the feeding interactions between perch and brown trout. In this context only a few references are available for British and Irish waters. Among them are Campbell (1955) and Thorpe (1974) in Scotland, Burrough & Kennedy (1978a,b) in England and Moriarty (1963) in Ireland.

Campbell (1955) observed in Loch Tummel (Scotland) that trout preferred trichopteran and chironomid larvae (30-40% of the stomachs examined) winged insects (23%), and Coleoptera, Plecoptera, Ephemeroptera, Crustacea (Gammarus, Asellus), young fish and Amphibia (10-20%). In the same work perch were reported to feed on the same items, but in different proportions. Campbell concluded that the feeding habits of perch differed from those of trout, particularly because the former fed on almost anything available, with the exception of surface food. The only period when both species were feeding vigorously on the same food was between late spring and early summer.

Moriarty (1963), investigating the food of perch and trout in Poulaphouca Reservoir (Ireland), found that 43 food-items were used by brown trout as against 27 by perch, and that both species used Caenis nymphs, Chironomus larvae and dipteran pupae in considerable quantities. He concluded that the perch prevent the trout from obtaining a full supply of necessary foodstuffs, as they consume larger quantities. However, no observations on the influence of this competition on trout growth were reported.

Thorpe (1974) showed that in Loch Leven (Scotland) the main foods used by perch were also important in the trout diet, particularly Asellus (in June) and Daphnia (in September). The investigation also demonstrated that during the summer, except for August, there was an overlap in the daily periods of most intense feeding activity of the two species. However, he suggested that despite the similarity of food-preferences, competition would only occur when a food-item was in short supply, and no evidence of this was observed during the study.

Burrough & Kennedy (1978) found that in Malham Tarn (England) the most important food-items in trout and perch diets were molluscs (particularly Lymnea pereger and pea mussels) and caddis larvae. However, they stated that there was no adequate evidence to support the idea that perch affect trout populations by competition, and that further studies were necessary to decide whether or not to remove the perch from Malham Tarn in order to improve trout production. In fact there were data to suggest that perch were more adversely affected than trout by competition in that situation.

V.2 Materials and Methods

V.2.1 Treatment of fish

Collection and treatment of perch were conducted as described in Chapter IV. In the laboratory fish were cut up and the stomachs removed, after which the stomach contents were preserved in 4% formalin for further analysis.

Studies on the food of trout were carried out using fish collected by angling. Immediately after capture, fish were weighed, measured and sexed. Then, as in perch, the stomachs were removed and the contents were placed in 4%

formalin for further investigation.

V.2.2 **Stomach contents analysis**

As discussed by Hynes (1970) and Windell & Brown (1978), analysis of stomach contents presents many problems and the various constraints dealt with in the literature were considered in selecting the methods used in this investigation. In particular, attention was paid to Ashmole & Ashmole (1967) who stipulated that any food analysis should include at least three methods of measurement.

Four methods of analysis were used in the present investigation. The first was the subjective method which consists of a subjective estimation by eye of the contribution of a food category to the diet. The estimate used was stomach fullness (Frost,1943; Rice,1962; Dipper et al,1977; Craig,1978) and it was scored by a points system as follows: 1-stomach 1/4 full with food; 2-stomach 1/2 full; 3-stomach 3/4 full; 4-stomach full; 5-stomach distended.

The second method used was volumetric and involved measurement of the volume by water displacement in a series of graduated cylinders of capacity varying from 10ml to 1000ml. To improve accuracy the stomach contents were blotted on filter paper (as advocated by Hyslop,1980) to remove excess water prior to volume determination.

The third method used was the numerical, which consists of counting the number of individuals in each food category (Hynes,1950; Guma'a,1978a; Crisp et al., 1978). This method is relatively simple and fast to operate when the identification of prey is possible (Hyslop,1980), but it is not suitable for items which do not occur in discrete units (Arawomo,1976).

The fourth method was frequency of occurrence which consists of estimating the proportion of stomachs containing each food class, regardless of quantity (Ashmole & Ashmole,1967).

V.3 Results and discussion

V.3.1 Food and feeding habits of perch from Cobbinshaw Reservoir

a) Size of food invertebrates eaten by perch

Table V.1 shows the monthly frequency distribution of the length of invertebrates eaten by perch in Cobbinshaw Reservoir and Fig.V.1 shows the overall percentage of length frequencies. The graph is self-explanatory and shows that it is mostly organisms between 0.5 and 1.0cm that are eaten by perch all the year round, followed by those between 0 and 0.5cm. Nevertheless, it is important to note that the results shown in Table V.1 and Fig.V.1 represent mainly benthic invertebrates and do not include zooplanktonic organisms. In fact the latter represent a very important food-item for perch of different ages, but because of their small size and great abundance they have been considered separately.

Table V.1 - Monthly length distribution of invertebrates eaten by perch from Cobbinshaw Reservoir excluding zooplankton (584 stomachs were analysed).

LENGTH GROUP (cm)	NUMBER PER MONTH								TOTAL
	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	
0.0-0.5	25	33	84	71	613	775	343	214	2158
0.5-1.0	450	612	1922	1227	5137	2610	1421	1089	14468
1.0-1.5	13	58	219	91	112	8	3	31	535
1.5-2.0	0	0	0	2	4	0	1	0	7
2.0-2.5	0	2	2	0	0	36	0	2	42
2.5-3.0	0	0	0	0	0	0	0	0	0
3.0-3.5	0	1	1	0	0	0	0	0	2
TOTAL	488	706	2228	1391	5866	3429	1768	1336	17212

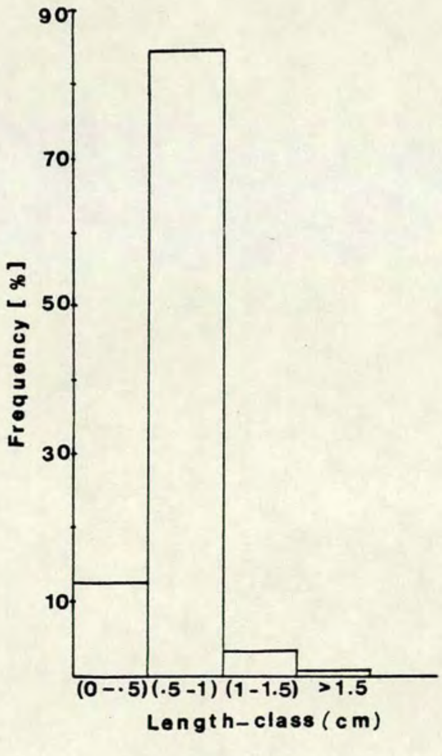


Fig. V.1 - Length frequency (%) histogram for invertebrates used by perch from Cobbinshaw Reservoir, excluding zooplankton.

The dominant invertebrate length-class observed in perch stomach contents,i.e. from 0.5 to 1.0cm, was not the predominant group in the bottom fauna. Instead, the latter was composed mainly of organisms between 0 and 0.5 (see page 87).

With regard to zooplankton feeding it was observed that Daphnia hyalina, the largest zooplankter found in Cobbinshaw Reservoir, was the most abundant in perch stomachs, whereas rotifers, the smallest and most abundant constituents of the zooplankton, were completely absent. Such observations reinforce the hypothesis of size-selective predation proposed by Galbraith (1967), Brooks (1968) and Guma'a (1978a).

Zooplankton represented the most important food for perch under one-year-old from Cobbinshaw Reservoir, particularly those of 0.2mm of length. One-year-old perch used a mixture of zooplankton, particularly larger Daphnia hyalina (over 2mm), and benthic animals such as Gammarus pulex and chironomid larvae of 0-0.5cm of length. Perch over two-years-old were found to feed on different size-class organisms, ranging from zooplankters to perch-fry.

Guma'a (1978b) observed that there was a linear relationship between maximum gape-height and total body-length of perch which was described by the equation: $G_{max} = 0.2152 + 0.0781\ L (r=0.99)$ where G_{max} is the maximum gape-height, L is the total length of the fish and r is the correlation coefficient. Such a relationship suggests that changes with age in the size of prey-items consumed is related to the increasing gape-height. This probably explains the results observed for perch in Cobbinshaw and elsewhere.

b) **Stomach fullness**

Stomachs of 973 perch were observed in order to investigate the occurrence of food based on the stomach fullness (SF) method. Results are shown in Table V.2 and Fig.V.2 for March to October, the months of intense feeding activity.

The number of distended stomachs (SF=5) was low (2.77%) over the whole observational period, but there was a predominance (30.63%) of fish with full stomachs (SF=4), followed respectively by fish with stomach-fullness of 3 (30.02%), 2 (17.57%) and 1 (12.13%). Only 6.88% of the fish had empty stomachs (SF=0) (Table V.2 and Fig.V.2).

Frequency of occurrence of empty stomachs reached its maximum value in April: of the 64 empty stomachs observed, 42 (62.69%) were recorded in this month (Table V.2). Such results suggest a decrease in feeding activity at this time. This suggestion is reinforced by the observation that in this month there was also a predominance of stomach-fullness 1 (25.68%) followed by 2 (19.67%), 3 (17.49%), 4 (10.93%) and 5 (3.28%). Figure V.2 also highlights the monthly variation in the number of empty stomachs. They decreased in May to reach a minimum in June, increased again to reach another but lower peak in August and then dropped to October when no empty stomachs were found.

In May there was a marked increase in feeding activity (Fig.V.2). Most of the stomachs (52.29%) were full (SF=4) and the frequency of distended stomachs (SF=5) was the largest observed (5.74%). In fact it seems that this month represented the period of most intense feeding activity for Cobbinshaw perch.

In June feeding activity decreased slightly, and then increased again in July when 55.38% of the stomachs were full, although no distended stomachs were recorded (Table V.2 and Fig.V.2). From August feeding decreased once more. In September and October there was a predominance of stomach fullness 3, respectively 47.5% and 34.42%.

Results obtained from Cobbinshaw Reservoir show that late spring and summer represent the most active feeding periods. Such observations are presumably related to the improvement in the environmental conditions at this time, namely increase of water temperature, daylight duration and availability of food items already discussed in chapters II and III.

Table V.2 - Monthly variation in the stomach-fullness of perch from Cobbinshaw Reservoir.

MONTH	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.	OCT.		
STOMACHS FULNESS									No.	(%)
0	4	42	3	1	3	12	2	0	67	6.88
1	8	47	5	12	8	19	5	14	118	12.13
2	14	36	20	44	14	21	13	9	171	17.57
3	21	32	45	69	33	33	38	21	292	30.02
4	5	20	91	38	72	39	19	14	298	30.63
5	0	6	10	0	0	5	3	3	2	2.77
TOTAL	52	183	174	164	130	129	80	61	973	100.00

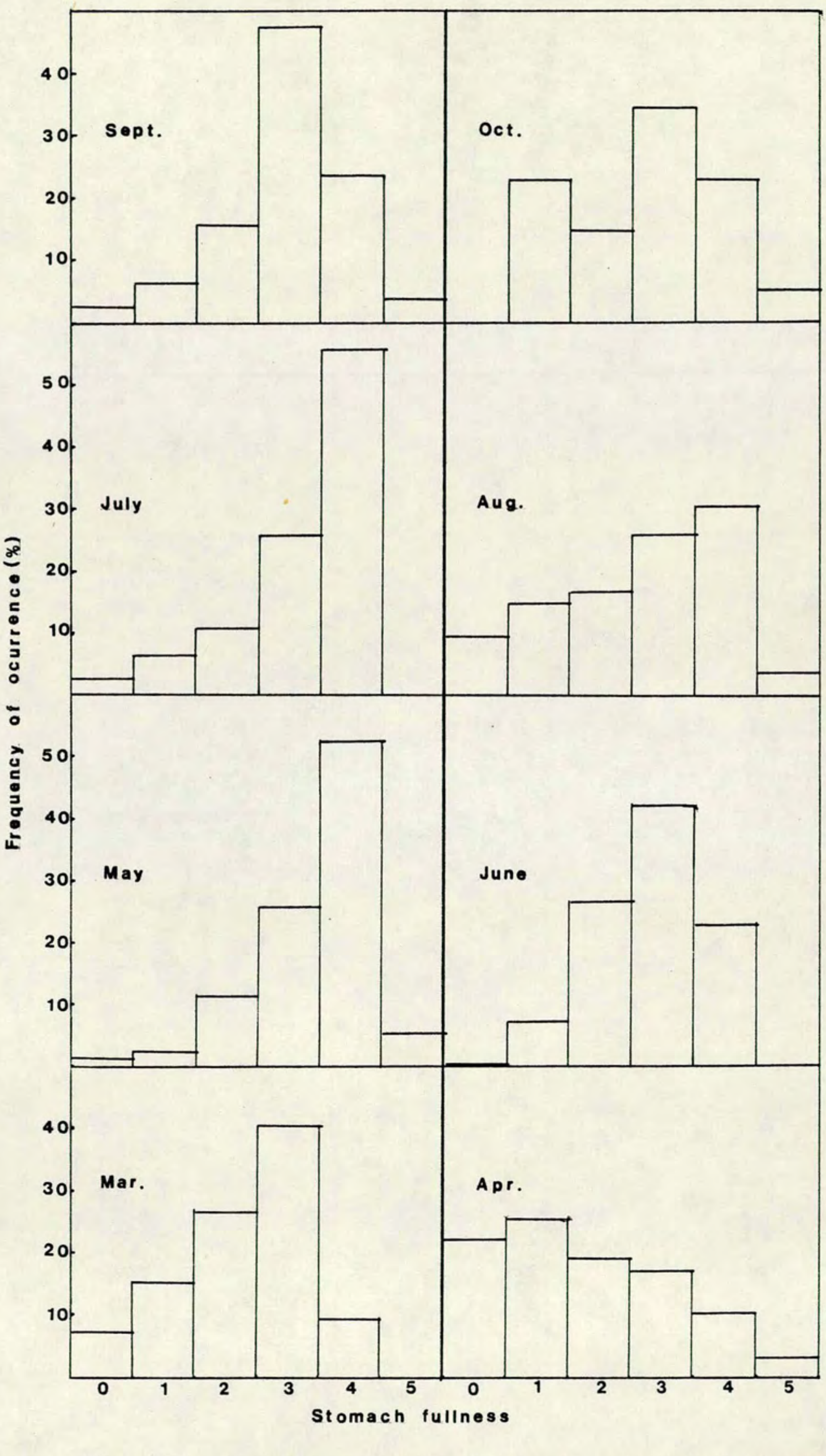


Fig. V.2 - Monthly variation (%) in the stomach fullness of perch.

The large proportion of empty stomachs recorded in April suggests a decrease in feeding activity in this period which corresponds to the spawning peak. The presence of some fishes with full stomachs at this period could be related to the occurrence, within the sample, of specimens which had already spawned and immature ones.

The literature contains constrasting observations on the feeding behaviour of perch during the spawning season. Keast (1968) stated that perch do not feed at spawning and similar results were recorded by Shilenkova (1959) in Lake Dzhalangash (U.S.S.R.). Nikitinsky, (1929), however, observed very active feeding before spawning in perch from Lake Zarizino (U.S.S.R.).

Information on stomach-fullness of perch from British waters is insufficient to draw conclusions about the matter. Nevertheless, it is worth mentioning the work of Craig (1978) who found that the widest range of organisms eaten by perch from Windermere occurred in May and June while the spawning period in this lake was regarded by him (1980) as being from the end of April until the first week in June. Such observations suggest, in contrast to Cobbinshaw Reservoir, an intensive feeding activity in Windermere during the spawning season.

In Cobbinshaw the intensive feeding activity in May possibly compensates for lack of feeding during the peak spawning time.

As shown in Table V.2 there was a slight decrease in feeding activity in June. This could be related to a rise in water temperature to over 26°C on some days, i.e exceeding the thermal optimal of the species of about 21-24°C (Neumann 1974). In fact, Neil & Magnuson (1974) showed in a tank experiment that perch preferred waters with temperature optima without food rather than extreme temperatures with food. Furthermore, the water level reached its lowermost level in this month, reducing at least the littoral area which constitutes the main source of food invertebrates by one-third. The decline in feeding activity observed in the autumn was probably due to impoverishment of environmental conditions associated with restriction of food comsumption at this time to maintenance level only, as proposed by Schneider (1973) and Thorpe (1974,1977b).

Another interesting aspect is the increase in the occurrence of empty stomachs in August. This is not a common observation for perch, although McCormack (1978) also recorded that the stomachs of 35% of Windermere's perch examined in August were empty. He found no reason for such results as there was no evidence of lack of food at that time.

c) Monthly variation in the diet composition

Contents of 584 stomachs were analysed to investigate patterns of monthly variation in diet composition. Table V.3 shows the stomachs with and without food. Appendix 5 shows the mean length and range of examined fish.

The food-items found during this investigation were:

1- Crustacea: Amphipoda (Gammarus pulex); Isopoda (Asellus aquaticus); Copepoda (Cyclops strenuus); Cladocera (Daphnia hyalina); and Ostracoda (Cypris spp).

2- Insecta: trichopteran larvae (Mystacides sp) and Limmnephilus sp); chironomid larvae and pupae (mainly Chironomus sp); megalopteran larvae (Sialis lutaria); adult aquatic insects (Hemiptera: Corixa faleni; Coleoptera, Platambus maculatus); adult insects (Trichoptera: Limnephilus sp.)

3- Mollusca: Potamopyrgus jenkinsi

4- Anellida: Oligochaeta (Tubifex tubifex and earthworms) and Hirudinea Glossiphonia sp.

5- Perch-fry and spawn

Table V.3 - Monthly variation in presence of food in perch stomachs.

MONTH	No.OF STOMACHS EXAMINED	STOMACHS WITH FOOD		STOMACHS WITHOUT FOOD	
		NUMBERS	%	NUMBERS	%
MARCH	52	49	94.23	3	5.77
APRIL	58	33	56.90	25	43.10
MAY	84	82	97.62	2	2.38
JUNE	82	82	100.00	0	0
JULY	78	78	100.00	0	0
AUGUST	94	85	90.42	9	9.58
SEPTEMBER	76	75	98.68	1	1.32
OCTOBER	60	60	100.00	0	0
TOTAL	584	544	93.15	40	6.85

Besides the living organisms, bottom sediments particularly small stones, plant remains, sticks and mud were also found in a small proportion of the stomachs.

Although the perch is usually described as a euryphagic fish, it is interesting to observe that in Cobbinshaw, as in most waters where its feeding habits have been investigated, there was a strong preference for a very restricted range of food-items, namely Gammarus pulex, Asellus aquaticus, zooplankton (Cladocera) and chironomid larvae and pupae. It seems that such organisms are selected by perch which will, however,switch to different food if they are not available.

The monthly variation in volume, number and frequency of occurrence of the following food-items in perch stomachs is shown in Table V.4: a)Gammarus pulex b)Asellus aquaticus c)zooplankton (Daphnia hyalina and Cyclops strenuus) d)trichopteran larvae (Mystacides sp. and Limnephilus sp.) e)winged insects (Corixa faleni, Platambus maculatus, Limnephilus sp.) f)chironomid larvae g)chironomid pupae h)perch-fry i)Bottom sediments (small stones, mud and plant remains) j)'Others': Ostracoda, Megaloptera larvae, Oligochaeta, leeches, fish spawn and unindentified organisms.

When the total volume for each item was pooled together (Table V.4) it was observed that Gammarus pulex was the most important (54.71%), followed by zooplankton (18.60%), Asellus aquaticus (10.20%), chironomid pupae (7.35%) and Chironomid larvae (1.72%).

Table V.5 shows the monthly variation in the number of organisms eaten by perch. In every month, with the exception of July, zooplanktonic organisms constituted the most numerous invertebrates. Nevertheless, this did not mean that they were the most important food-items since due to their small size their volumes were not comparable to those of larger crustaceans, insects, etc. In fact the numerical method was not a very good way to investigate monthly variation in food invertebrates eaten. Therefore, analysis were carried out mainly by using the frequency of occurrence and volumetric methods.

Table V.6 and Fig.V.3 show the frequency of occurrence and Fig.V.4 shows the percentage of volume of the main food-items found in perch stomachs.

__Gammarus pulex__ was the most important food-item. It represented the major bulk from April to October (Fig.V.4 and Table V.4). In March it was the second in volume (Fig.V.4) but the first in occurrence (Fig.V.3 and Table V.6). In September and October it appeared in very high concentrations, respectively, in 73.04% and 77.46% of the stomachs (Table V.4).

__Asellus aquaticus__ represented the major bulk in March (Fig.V.4) when it was the second highest in occurrence (Table V.6 and Fig.V.3). Its volume in the stomachs decreased from April to June, increased from July to August, decreased once more in September and increased again in October.

Zooplanktonic organisms were not very important in bulk in March (Fig.V.4). This month represented the only period in which <u>Cyclops strenuus</u> was more numerous (mean number of 60.0 individuals/fish) than <u>Daphnia hyalina</u> (mean number of 7.05 individuals/fish) (Table V.5). From April to June, however, zooplanktonic organisms represented the second place in volumetric importance, (Fig.V.4) and in May they were actually the food-items of most frequent occurrence, appearing in 71.43% of stomachs (Table V.6). In July they almost disappeared from the stomachs (Fig.V.4) but after August became again the second most important item in volume and appeared in 37.23% (August), 72.37% (September) and 50% (October) of the stomachs (Table V.6).

The contribution of **chironomid larvae** to the bulk was low in March and April (Table V.4 and Fig.V.4). Then it increased until July when it reached its peak (5.85% of volume) (Table V.4). In this month chironomid larvae appeared in 80.77% of stomachs (Table V.6); thereafter their volume in the diet decreased considerably.

Chironomid pupae were first recorded in the stomachs in May (Table V.6 and Fig.V.3). At this time they repesented the fourth most important food-item (5.63% of the volume) (Fig.V.4) with a frequency of occurrence of 28.57% (Table V.6). After June their contribution to the volume increased to reach a maximum in July (29.88%) when they were the second most important food, appearing in 84.61% of the stomachs. Afterwards their volumetric importance decreased until they disappeared in October.

As shown in Tables V.4, V.5 and V.6 **other invertebrates** contributed to the food volume in perch stomachs in

Cobbinshaw Reservoir. Nevertheless, they appeared occasionally and did not give a consistent contribution to their diet. These organisms were Trichoptera which had its maximum contribution in June (3.23% of the bulk, Mollusca with 0.09% of the volume in May, winged insects (2.79% in June) and 'others' (3.35% in April) (Table V.4).

Perch-fry were not an important food-item. They appeared only in June in 10.97% of the stomachs examined, (Table V.6), with a contribution of 7.78% of the volume (Table V.4).

Table V.4 - Variation in the volume in ml (and percentage) of food items eaten by perch

Month / Organism	March	April	May	June	July	August	September	October	Total
A. aquaticus	1.583 (39.36)	2.283 (19.05)	2.175 (8.61)	0.590 (4.64)	1.557 (8.72)	3.934 (17.07)	0.578 (2.13)	1.692 (8.89)	14.392 (10.20)
G. pulex	1.456 (36.20)	5.656 (47.21)	11.530 (45.67)	5.211 (41.04)	8.284 (46.38)	10.432 (45.28)	19.832 (73.04)	14.748 (77.46)	77.149 (54.71)
Trich. larvae	0.050 (1.24)	0 (0)	0.553 (2.19)	0.410 (3.23)	0.348 (1.95)	0.398 (1.73)	0.450 (1.66)	0 (0)	2.20 (1.57)
Mollusca	0.002 (0.05)	0 (0)	0.024 (0.09)	0.002 (0.01)	0.006 (0.03)	0.011 (0.05)	0.001 (0)	0 (0)	0.04 (0.03)
Perch-fry	0 (0)	0 (0)	0 (0)	0.988 (7.78)	0 (0)	0 (0)	0 (0)	0 (0)	0.988 (0.70)
Winged insects	0 (0)	0.150 (1.25)	0.030 (0.12)	0.354 (2.79)	0.070 (0.39)	0.140 (0.61)	0.050 (0.18)	0.450 (2.36)	1.244 (0.88)
Zooplankton	0.222 (5.52)	3.359 (28.03)	8.112 (32.13)	2.406 (18.95)	0.153 (0.86)	4.088 (17.74)	5.791 (21.33)	2.111 (11.09)	26.242 (18.60)
Chir. larvae	0.012 (0.30)	0.010 (0.08)	0.573 (2.27)	0.362 (2.85)	1.045 (5.85)	0.326 (1.41)	0.068 (0.25)	0.026 (0.14)	2.422 (1.72)
Chir. pupae	0 (0)	0 (0)	1.421 (5.63)	1.331 (10.48)	5.336 (29.88)	2.258 (9.80)	0.019 (0.07)	0 (0)	10.365 (7.35)
'Others'	0 (0)	0.401 (3.35)	0.567 (2.24)	0.110 (0.87)	0.049 (0.27)	0.099 (0.43)	0.135 (0.50)	0 (0)	1.36 (0.96)
Bottom sediment	0.68 (16.91)	0.032 (0.271)	0.203 (0.80)	0.913 (7.19)	0.966 (5.41)	1.294 (5.62)	0.222 (0.82)	0 (0)	4.31 (3.05)

Table V.5 - Monthly variation in the mean number (± s) of food items eaten by perch from Cobbinshaw Reservoir

Month	March N=52	April N=58	May N=84	June N=82	July N=82	August N=94	September N=76	October N=60
Organism								
A. aquaticus	6.30±8.28 (328)	4.25±11.00 (247)	3.19±10.13 (248)	1.08±4.48 (89)	2.34±8.02 (183)	6.56±37.27 (356)	1.35±4.92 (103)	3.63±23.97 (218)
G. pulex	2.86±4.52 (148)	7.27±18.86 (422)	10.14±21.8 (852)	4.58±14.60 (376)	7.09±16.53 (553)	8.35±20.54 (788)	19.77±50.20 (1503)	18.12±55.30 (1091)
D. hyalina	7.05±28.95 (386)	301.9±771.8 (13.390)	1,155.70±1,325.0 (93,583)	322.64±807.75 (26,457)	22.80±156.87 (1,779)	536.86.±963.05 (50,465)	906.92±931.97 (68,926)	436.35±877.63 (26,181)
C. strenuus	60.0±151.14 (3.120)	1.37±10.41 (80)	22.46±67.86 (1,887)	29.7±60.24 (2,437)	2.82±14.87 (220)	4.58±36.57 (431)	0.44±3.90 (34)	14.76±33.10 (886)
Trich. larvae	0.02±0.10 (1)	0 (0)	0.03±0.08 (3)	0.06±0.28 (5)	0.05±0.22 (2)	0.05±0.33 (5)	0.03±0.25 (3)	0 (0)
Winged insects	0 (0)	0.07±0.31 (4)	0.01±0.05 (1)	0.30±2.32 (25)	0.05±0.22 (4)	0.02±0.14 (2)	0.01±0.11 (1)	0.67±0.25 (4)
Chir. larvae	0.23±0.54 (9)	0.17±0.93 (10)	2.60±9.75 (217)	2.30±9.56 (189)	24.47±42.67 (1,909)	5.86±20.5 (551)	1.75±9.36 (133)	0.35±1.63 (21)
Chir. pupae	0 (0)	0 (0)	10.20±40.99 (855)	8.51±20.74 (698)	40.79±43.35 (3,182)	15.0±35.75 (1,410)	0.14±1.15 (11)	0 (0)
Mollusca	0.04±0.10 (2)	0 (0)	0.04±0.10 (4)	0.02±0.15 (2)	0.08±0.31 (6)	0.07±0.55 (7)	0.01±0.11 (1)	0 (0)
'Others'	0 (0)	0.39±2.86 (23)	0.57±1.89 (48)	0.08±0.47 (7)	0.34±1.04 (27)	0.52±3.66 (49)	0.17±1.17 (13)	0.03±0.25 (2)

s = standard deviation

Table V.6 - Frequency of occurrence and (percentage) of main food items eaten by perch

Month / Organism	March	April	May	June	July	Aug.	Sept.	Oct.
A. aquaticus	32 (61.54)	17 (29.31)	30 (35.71)	14 (17.07)	22 (28.20)	15 (15.96)	15 (19.74)	14 (23.33)
G. pulex	34 (65.38)	21 (36.21)	36 (42.86)	18 (21.95)	32 (41.02)	31 (32.98)	26 (34.21)	20 (33.33)
Trich. larvae	1 (1.92)	0 (0)	3 (3.57)	9 (10.97)	4 (5.12)	4 (4.25)	2 (2.63)	0 (0)
Mollusca	2 (3.85)	0 (0)	1 (1.19)	2 (2.44)	5 (6.41)	2 (2.13)	1 (1.31)	0 (0)
Perch fry	0 (0)	0 (0)	0 (0)	9 (10.97)	0 (0)	0 (0)	0 (0)	0 (0)
Winged insects	0 (0)	3 (5.72)	1 (1.19)	5 (6.10)	4 (5.12)	2 (2.13)	1 (1.31)	4 (6.66)
Zooplankton	9 (17.30)	11 (18.96)	60 (71.43)	43 (52.44)	11 (14.10)	35 (37.23)	55 (72.37)	30 (50.0)
Chir. larvae	7 (13.46)	4 (6.90)	26 (30.95)	9 (10.97)	63 (80.77)	20 (21.28)	7 (9.21)	7 (11.67)
Chir. pupae	0 (0)	0 (0)	24 (28.57)	32 (39.02)	66 (84.61)	25 (26.60)	2 (2.63)	0 (0)
'Others'	0 (0)	2 (3.44)	11 (13.09)	4 (4.88)	12 (15.38)	14 (14.89)	3 (3.95)	1 (1.66)
No. stomachs examined	52	58	84	82	78	94	76	60

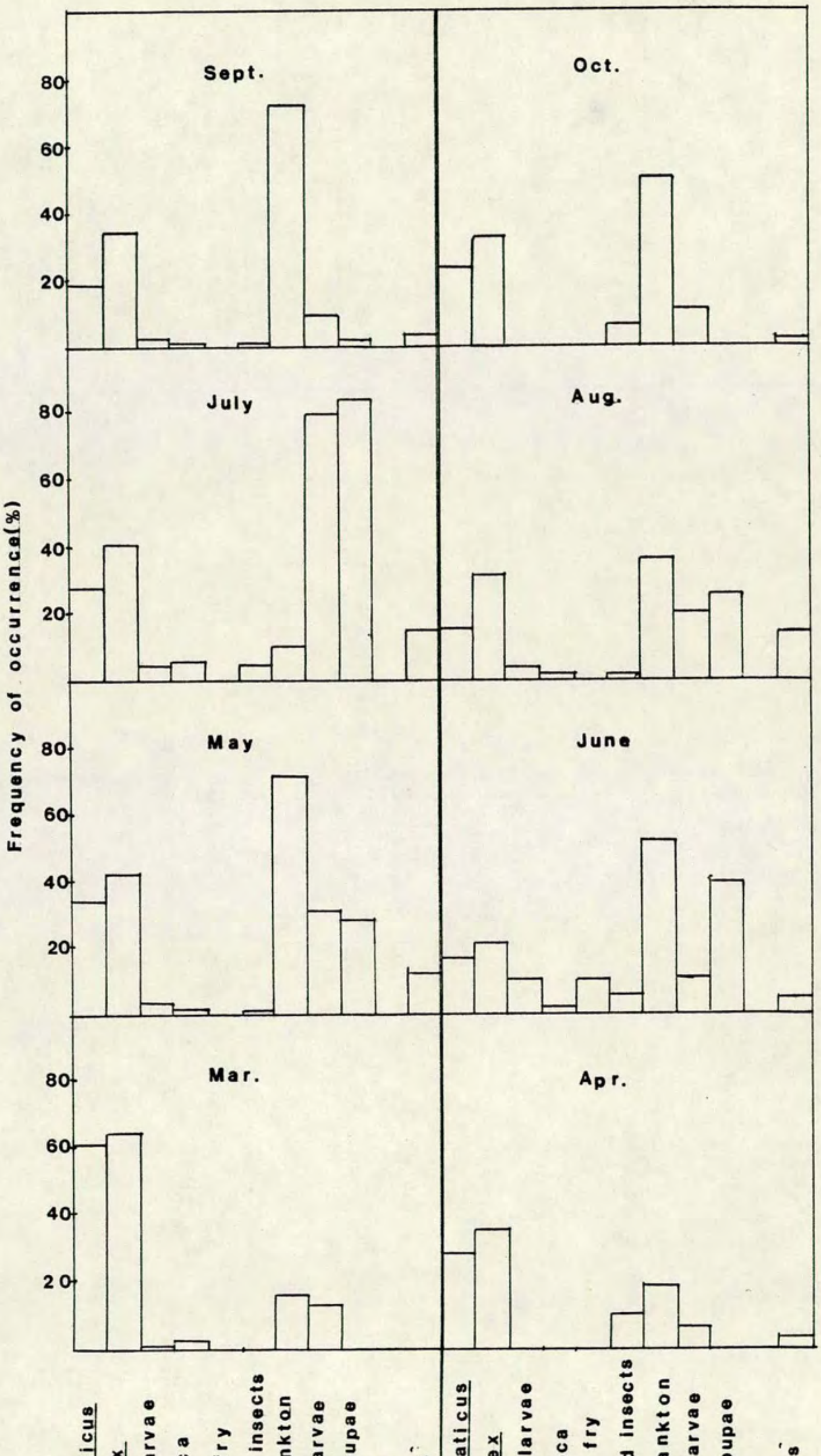


Fig.V.3 - Monthly variation of frequency of occurrence (%) of main food, items eaten by perch.

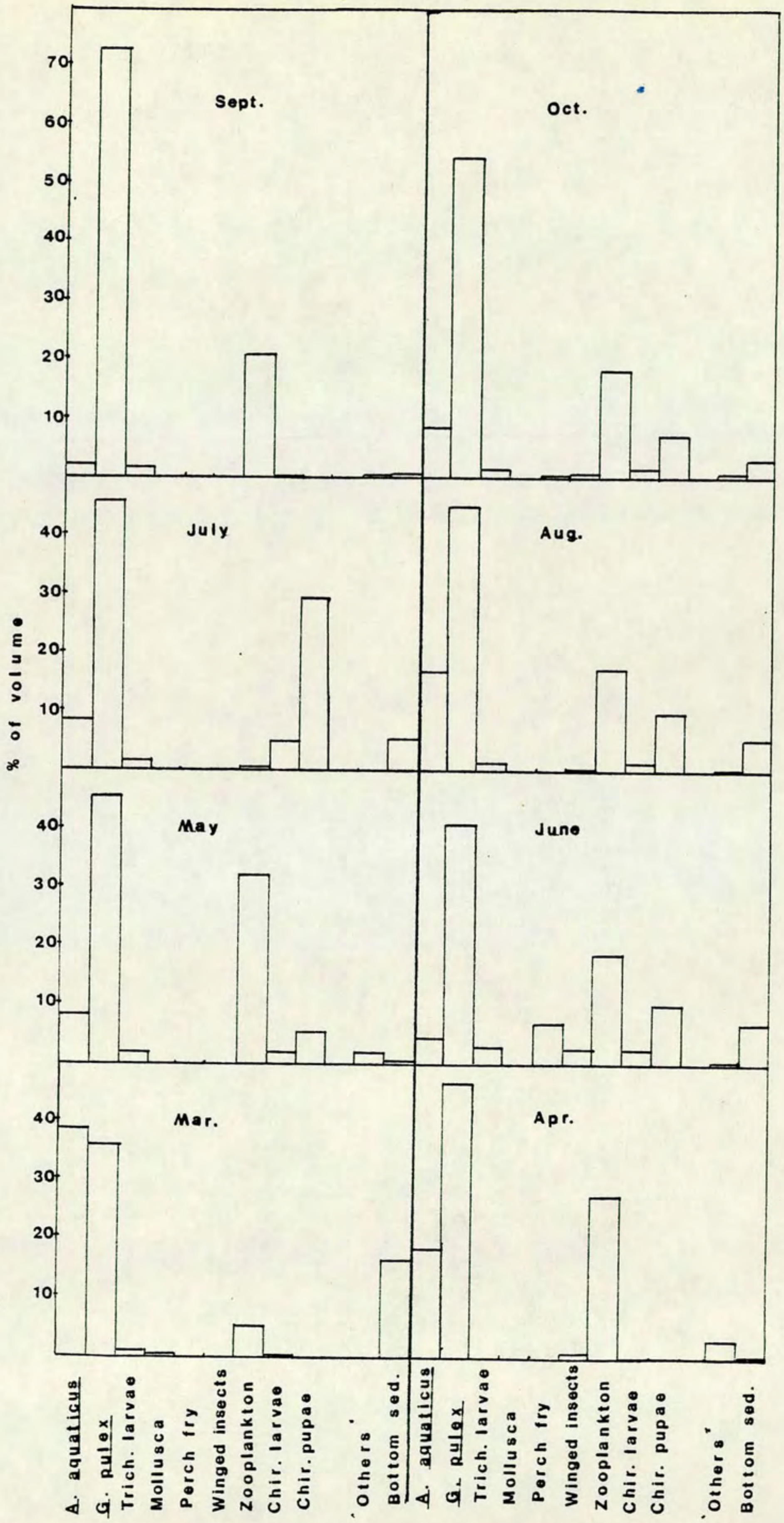


Fig.V.4 - Monthly variation of volume (%) of main food-items eaten by perch.

Bottom sediments were observed in many stomachs particularly in March when they constituted 16.91% of the volume (Table V.4). In April they were almost absent and from May they increased to reach a maximum of 7.19% in June. After this their contribution to the volume decreased until they became absent in October.

It seems that in March, because of the low water temperature, the perch preferred the deeper water. At this time considerable amounts of bottom sediments were recorded in their stomachs. Asellus aquaticus was the dominant food organism together with Gammarus pulex and apparently the first was taken from the weed-beds between the gravelly littoral and the black mud areas. Evidence for this statement was found by comparing the kind of sediments present in the stomachs with those in the relevant areas.

In April the water becomes warmer and due to their migratory spawning behaviour the perch seek spawning sites in gravelly and weedy areas the exact localities in which Gammarus pulex is abundant and this organism becomes the dominant food-item, particularly in the phase of intense feeding which follows spawning.

In June there was a slight decline in feeding activity associated with a change in the diet. As discussed previously higher temperatures, decrease in feeding area because of lowered water level, and blooms of blue-green algae might possibly also be responsible for such changes. Presumably such impoverishment of environmental conditions could lead to open-water feeding and utilization of new food sources, viz: - the perch-fry and the chironomid pupae (now on their way to the water surface for adult emergence). In this context it is interesting to observe that the concentration of Daphnia hyalina is drastically reduced in July in the water (Fig.III.3 - Chapter III) and in the stomach contents (Table V.5) possibly due at least in part to predation by perch. Decline of Daphnia in summer in Lake Ontario (Canada) was also attributed to fish predation by Hall (1971).

Perch-fry were not found in the stomach contents after August as they had presumably grown too large for the gape-height of adults. From now onwards feeding on Gammarus pulex and zooplankton became even more intensive, particularly after September when chironomid pupae disappeared completely.

It is quite clear that the response of perch to prey movement is an important factor affecting their feeding habits. It is possible that the preference of Cobbinshaw perch for Gammarus pulex, Daphnia hyalina, perch-fry and chironomid pupae is related to the movement patterns of these organisms. Boulet (1958) observed that speed, form of trajectory, size and shape of objects were important factors in releasing responses and receptivity of perch and that Daphnia-like movements were particularly attractive to the fish.

Deedler (1951) observed that hunting in shoals in open water was successful when the perch could keep its prey in sight and that in the absence of fish-fry, perch searched plants for small animals sheltered by them.

Perch show morphological adaptations which permit them to ingest different sizes of organisms. Ingestion of larger organisms is facilitated by the presence of backwardly facing teeth lining the jaws, whereas zooplanktonic organisms are ingested by filtration through the comb-like rakers formed by the inner edges of the gills. In the latter context the size of ingested zooplankters is supposed to be related to the gill-raker spacing. Galbraith (1967), for instance, found that perch were very size-selective in their feeding and usually consumed Daphnia above 1.3mm long.

No attempts have been made to measure gill-raker spacing of perch from Cobbinshaw. But in this context it was observed that most of the Daphnia hyalina present in the stomach and in the zooplankton were above 2.0mm(Page 74). However, in addition to the normal filtration of zooplankton by the gill-rakers, a process of 'bulk-swallowing' may also occur when the plankton is particularly concentrated - rather in the way one swallows soup.

The parasite Echinorhynchus truttae was recorded in the perch stomachs throughout the period studied but in low number. E. truttae has been recorded as a perch parasite (Campbell,1974) but it is unlikely that they are causing any harm to Cobbinshaw perch since fish containing these organisms were always in good condition.

Acanthocephala were recorded in the bottom fauna, where they occur free for a short time before infecting crustaceans, but apparently they are not eaten by perch. It seems that they parasitize Asellus aquaticus and when perch eat these latter organism they also ingest the larval Acanthocephala.

Plate 4 shows some specimens of A. aquaticus found in a perch stomach being parasitized by Echinorhynchus truttae and Fig.V.5 shows the relationship between the numbers of A. aquaticus, and those of E. truttae present in perch stomachs.

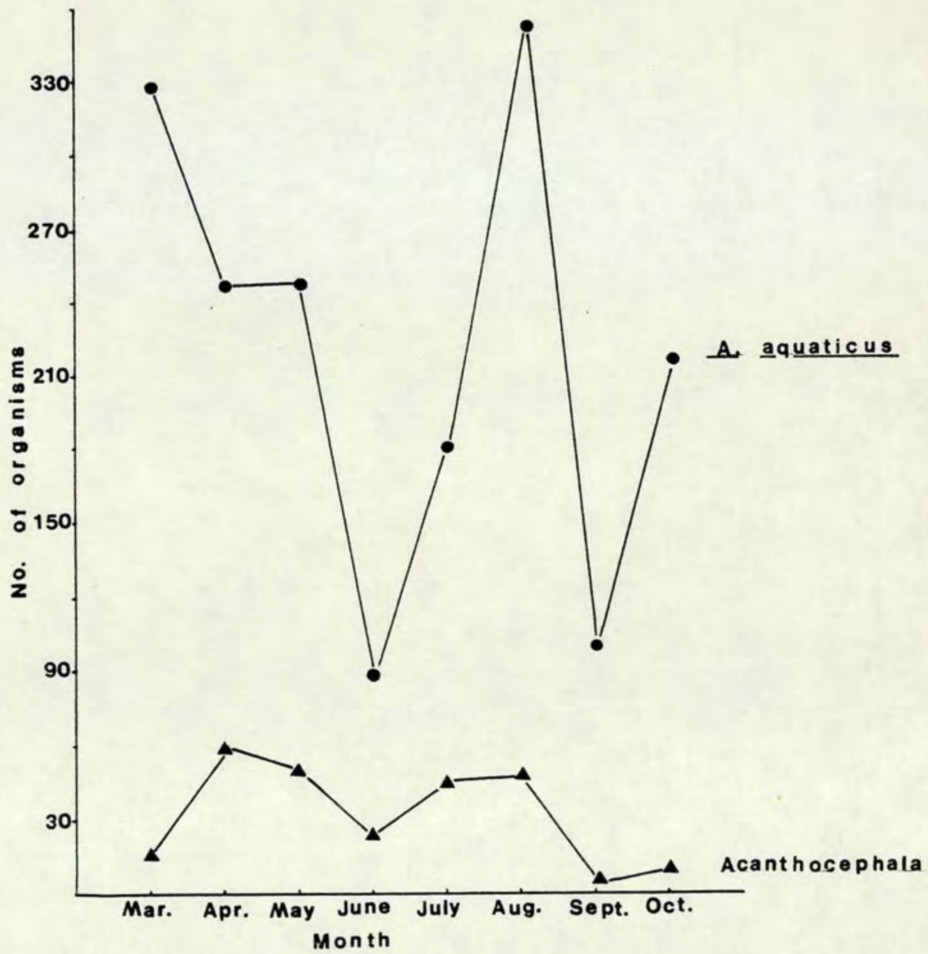


Fig. V.5 - Monthly variation in the mean number of Acanthocephala and Asellus aquaticus in perch stomachs.

V.3.2 **Food and feeding habits of trout**

a) Stomach fullness

To study the food of trout 338 stomachs of fish caught by angling during the 1982 season (1 April - 30 September) were examined.

Most of these stomachs were from two and three-year-old fish, with a predominance of the former. During the period of the study very few fish were found with empty stomachs (Table V.7).

Table V.7 also shows the monthly variation in mean stomach fullness. This figure increased from April to May and then decreased until it reached a minimum in August. After this it increased suddenly to its maximum value in September.

Figure V.6 shows the monthly variation in the stomach fullness expressed as a percentage of total stomachs each month. Stomachs $\frac{3}{4}$ full (SF=3) were most frequent (37.87%) followed by SF=4 (26.02), SF=2 (19.53), SF=5 (4.73) and SF=0 (2.37%). August was the only month in which empty stomachs were recorded (14.28% of the total stomachs examined). In this context it is interesting to observe that in this month a large number of full stomachs (including SF=5) were also recorded (Fig.V.6), although such stomachs contained food considered of low nutritive value (e.g. bottom sediments).

Trout are reported to feed all the year round on a diet which varies seasonally according to environmental conditions and the life-cycle of food invertebrates. This is supported by the results obtained in Cobbinshaw Reservoir. It seems that there was a close relationship between the feeding habits of trout and variation in water temperature. Thus in April when the water became warmer, the trout started their migration to deeper water. However, because of the occurrence of some cold days at this time and the fact that the littoral area was still almost entirely covered by water the diet was divided between bottom littoral food-items (particularly trichopteran larvae, Gammarus pulex and Asellus aquaticus) and open water organisms (zooplankton and terrestrial insects).

Table V.7 - Monthly variation in the stomach fullness of trout

MONTH	No. STOMACH EXAMINED	STOMACH WITH FOOD		STOMACH FULLNESS
		Nos.	%	mean ± s
April	52	52	100	2.77 ± 1.10
May	72	72	100	3.03 ± 0.97
June	52	52	100	2.92 ± 1.09
July	44	44	100	2.81 ± 0.96
August	56	48	85.71	2.61 ± 1.18
September	62	62	100	3.26 ± 0.63

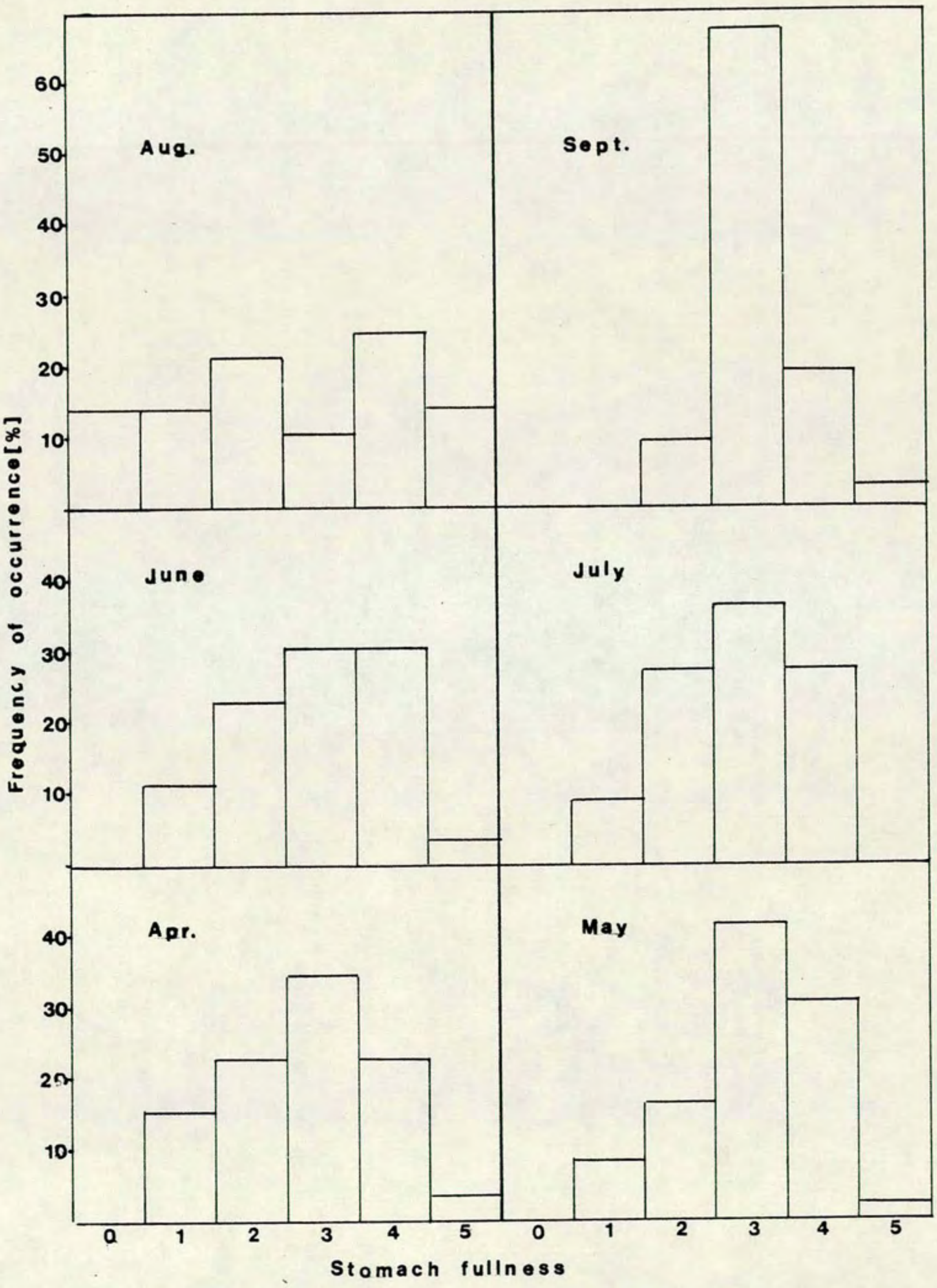


Fig. V.6 - Monthly variation in the stomach fullness of trout.

Intensive feeding was observed in May and is probably due to the spring improvement in food availability, particularly because of the emergence of adult terrestrial insects which fall into the water in great numbers. After June, impoverishment of environmental conditions (i.e occurrence of higher temperatures, lowering of water levels, blooms of blue-green algae and decreases in the zooplankton) produced a reduction in feeding activity. At this time perch-fry are another food alternative, but presumably due to their rapid growth they become unsuitable from August onwards and in this month activity levels of trout decrease slightly and some empty stomachs are found. This situation probably leads to consistent bottom feeding with occasional rising for hunting terrestrial insects. In this period intensive feeding on two food-items was observed, namely fish pellets, which presumably penetrated through the mesh of rearing cages sited in the reservoir, and pieces of stick - these unusual items are discussed in the next section.

b) Size of invertebrates eaten by trout

Figure V.7 shows the length distribution of non-zooplanktonic food-items eaten by trout. Trout, like perch, preferred organisms belonging to the 0.5-1.0cm length classes, although the dominant length among benthic invertebrates was 0-0.5cm. The figure does not include zooplanktonic organisms. In fact when these were considered there was a predominance of the 0-0.5cm length-class during April and May when zooplankton was important in the diet.

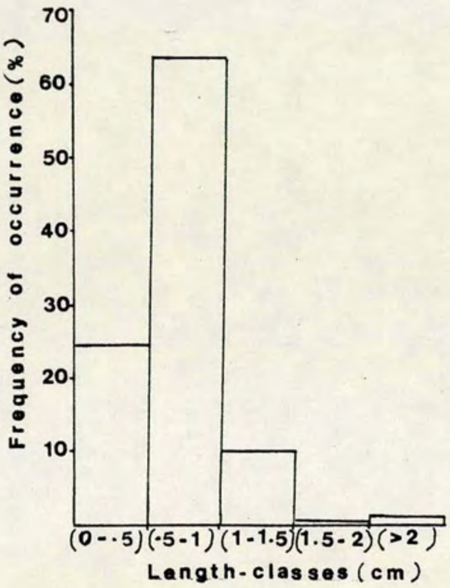


Fig. V.7 - Length frequency classes of food-items eaten by trout from Cobbinshaw Reservoir.

In this context it is interesting to observe that in April and May there was a dominance of 0.5-1.0cm organisms (excluding zooplankton), mainly due to the dominance of trichopteran larvae, winged insects, and benthic crustaceans.

In June perch-fry were the principal food-item and a dominance of 1-1.5cm organisms was observed. After July 0.5-1.0 cm organisms predominated once again.

c) Monthly variation in composition of diet

Identification of food-organisms was attempted whenever possible. In most cases it was not practicable to obtain determinations to specific level, due to the macerated state of the stomach contents, particularly in the case of winged insects which were often identified only to family.

Keys used in the identification of invertebrates have already been mentioned in Chapter III.

Variation in the mean number, percentage by volume and frequency of occurrence of food-items eaten by trout are shown in Table V.8, Figs. V.8 and V.9 respectively.

The diet composition was characterized as follows:

Mollusca

These organisms showed the highest presence frequency in stomach in April. However, their peak in numbers and volume occurred in August. April and May showed Lymnaea pereger as the commonest species. After June Potamopyrgus jenkinsi and Pisidium sp. were the most numerous. Valvata sp. appeared occasionally in April. The largest number of mollusca recorded for one trout was in August when 572

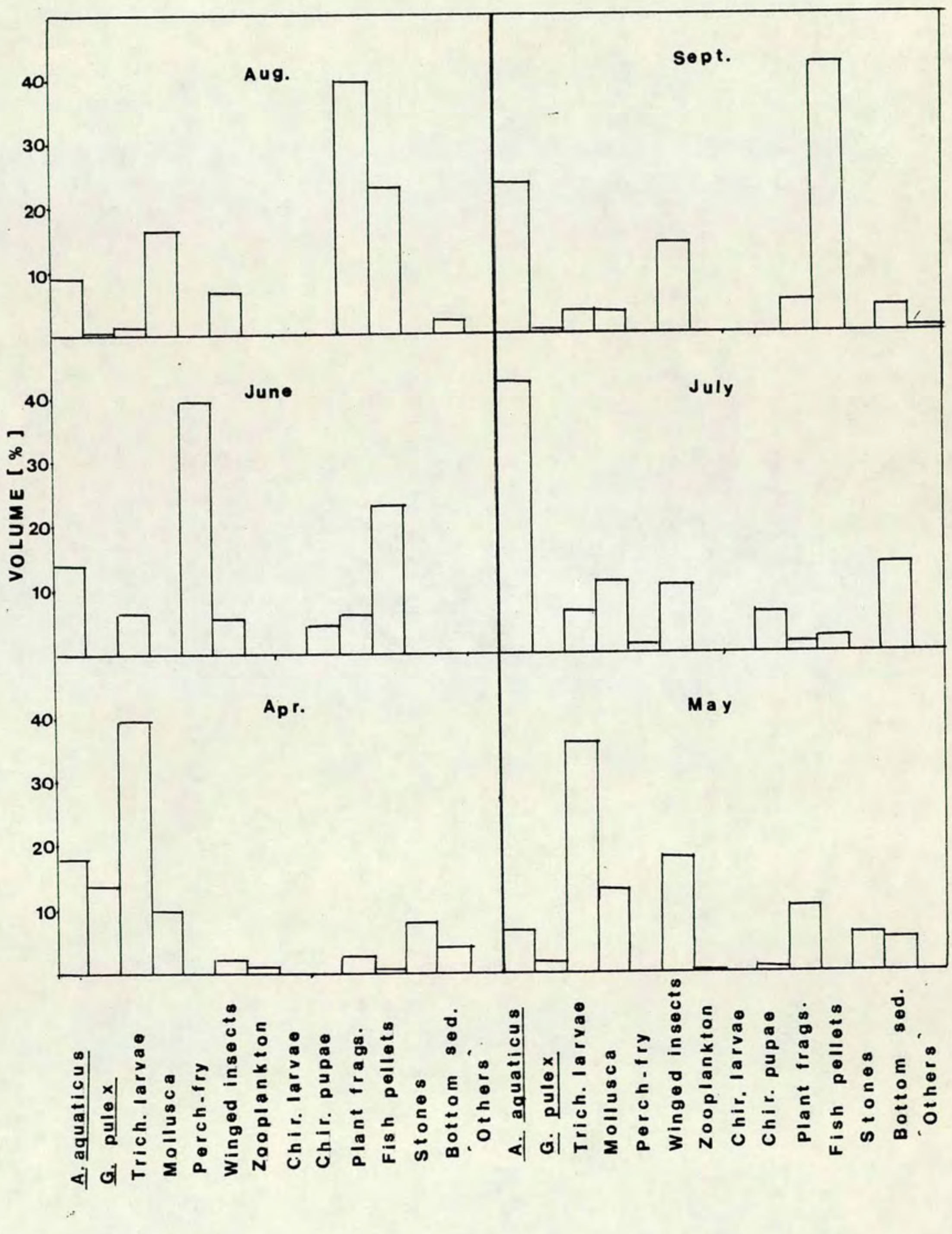


Fig. V.8 - Monthly variation of volume (%) of main food-items eaten by trout.

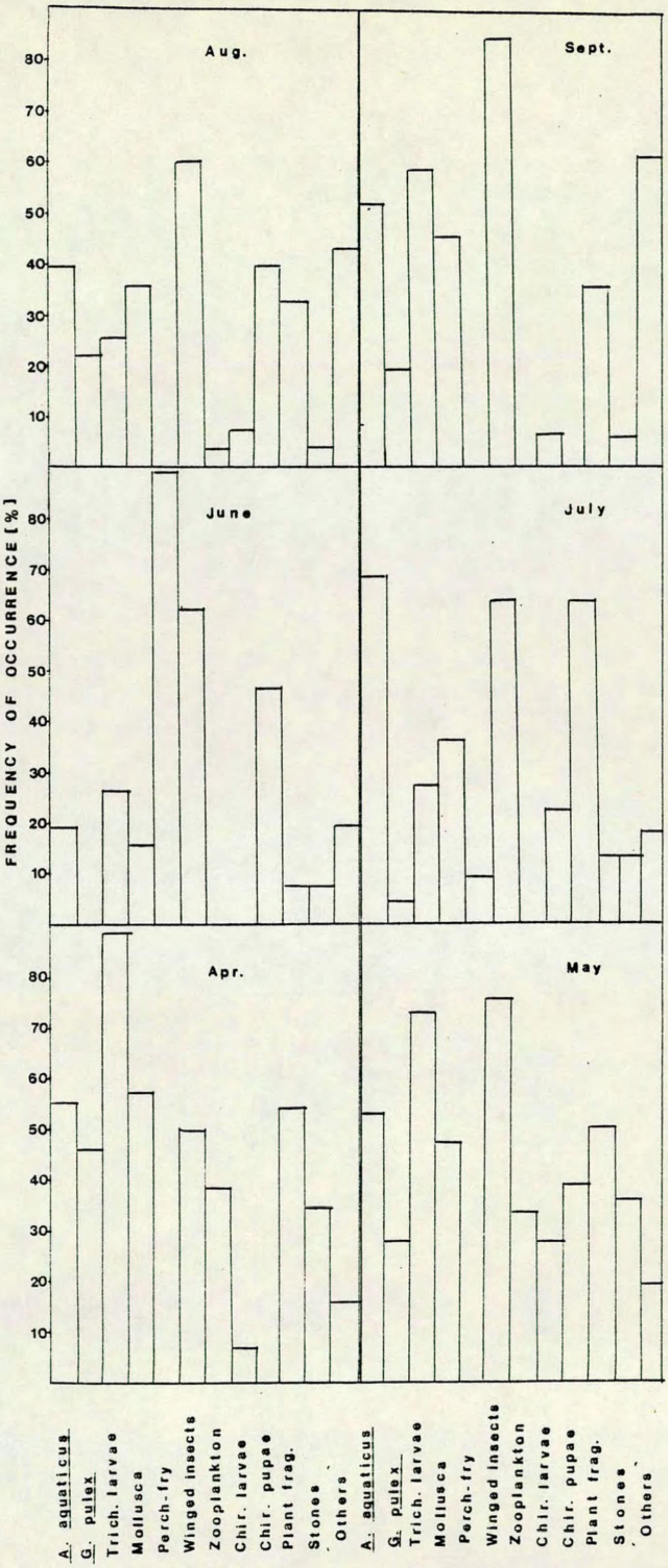


Fig. V.9 - Monthly variation of frequency of occurrence (%) of main food-items eaten by trout.

Table V.8 - Monthly variation in the mean number (± s) of food items present in the stomach of trout from Cobbinshaw Reservoir

Month	April	May	June	July	August	September
Organisms						
A. aquaticus	29.08 (±40.87)	16.89 (±34.70)	15.58 (±77.0)	70.54 (±167.61)	39.86 (±88.07)	97.42 (±201.75)
G. pulex	21.96 (±46.07)	3.44 (±9.85)	-	0.73 (±3.41)	0.50 (±1.07)	2.74 (±9.46)
D. hyalina	264.50 (±697.41)	121.53 (±306.71)	-	-	1.43 (±7.56)	-
C. strenuus	0.38 (±1.96)	2.78 (±15.04)	-	-	-	-
Trich. larvae	25.69 (±46.0)	25.25 (±53.13)	0.81 (±1.94)	0.82 (±1.71)	0.68 (±1.31)	1.97 (±2.89)
Winged insects	2.11 (±3.33)	27.97 (±47.86)	2.54 (±3.86)	4.09 (±8.47)	5.11 (±9.86)	56.42 (±82.19)
Chir. larvae	0.61 (±2.94)	0.67 (±1.49)	-	0.68 (±1.52)	0.18 (±0.67)	0.13 (±0.56)
Chir. pupae	-	9.11 (±30.89)	2.92 (±5.92)	9.64 (±25.27)	1.61 (±4.13)	-
Mollusca	12.58 (±27.28)	9.06 (±18.01)	0.38 (±1.39)	14.54 (±42.75)	32.36 (±105.86)	3.61 (±6.12)
Perch-fry	-	-	28.08 (±35.99)	0.27 (±0.93)	-	-
Plant frag.	2.65 (±3.75)	2.75 (±4.11)	1.15 (±4.41)	0.50 (±1.74)	14.39 (±45.61)	5.87 (±16.02)
Stones	7.50 (±22.79)	6.31 (19.19)	0.38 (±1.77)	0.18 (±0.50)	0.11 (±0.57)	0.65 (±0.25)
'Others'	0.54 (±1.42)	0.22 (±0.48)	0.19 (±0.40)	0.45 (±1.50)	0.89 (±1.75)	3.19 (±6.81)

s = standard deviation

specimens of Pisidium sp. were found in a single stomach.

Annelida

This phylum was represented by Oligochaeta with two unidentified species and Hirudinea (Glossiphonia sp). Because of their low number and occasional occurrence they were summed with other organisms and included in the group 'others' (Table V.8).

Oligochaeta are usually reported as being poorly represented in the trout diet - this is probably a consequence of their burrowing behaviour. One of the Oligochaeta species encountered was an earthworm which was very frequent in stomachs in September after a rise in water-level.

Insecta

Insects represented a very important food-item in trout stomachs. Trichopteran larvae, chironomid larvae and pupae, and other winged forms constituted the most important groups and are considered separately below.

Trichopteran larvae were the most consistent and numerous insects, in the stomachs - numerically they were the second most important benthic invertebrate (Table V.8) and the most important when measured by volume and percentage occurrence (Figs. V.8 and V.9). Arthripsodes sp. was the most abundant and frequent and was followed by

Lymnephilus sp. These two genera were common in the stomachs of trout feeding in the littoral area. Mystacides sp. was less frequent and occurred particularly in the stomachs of trout feeding on the black muddy bottom; this species was among the largest organisms eaten (>3cm).

The importance of trichopteran larvae decreased from April to June, increased slightly in July, decreased in August and increased again in September. Such variation is related to trout feeding behaviour discussed later in this chapter and to the life cycle of trichopterans discussed in Chapter III.

Chironomid larvae were represented mainly by Chironomus. They were recorded from April to September, with the exception of June. Their peak of occurrence was in May when they appeared in 27.77% of the stomachs (Fig.V.9). Nevertheless, their volumes and numbers were low all the year round (Table V.8 and Fig.V.9).

Chironomid pupae: were recorded only from May to September as a result of their life cycle. Their highest value was recorded in July (Table V.8 and Fig.V.9).

Winged insects were represented by a large number of species including terrestrial and aquatic forms with a very short adult life. Occurrence of species in the diet varied almost weekly, according to the season of adult emergence.

In most cases it was not possible to identify them to species but a list of the main families and more accurate determinations where available, are presented in Appendix 3.

Winged insects were more frequent in September when they appeared in 83.87% of stomachs. However, they occurred in very high concentrations in May as well (Table V.8 and Figs. V.8 and V.9). In April, June, July and August they were of frequent occurrence but their volume was comparatively low (Table V.8 and Figs. V.8 and V.9).

Presence of a large numbers of winged insects of a black colour suggests that black insects are more attractive to trout than others. In fact Frost & Brown (1972) pointed out that the black fly (Simulium spp.) is one of the most important Diptera in the trout diet. These organisms were not common in Cobbinshaw's trout stomachs since they are rare in the area. However many 'black flies' were consumed particularly the Bibionidae (Dilophus febrilis) which in September represented the winged insect present in the greatest volume: 367 specimens of this species were recorded in a single stomach.

Crustacea

These organisms constitute one of the most important items in the diet of trout, and appear all the year round.

Asellus aquaticus was the most common and abundant crustacean in the stomachs and were the second highest organism by volume (Fig.V.8). Their volumes decreased in May but increased again in June. In July they were the most important food-item appearing in 68.18% of the stomachs and providing 42.61% of the total volume (Figs.V.8 and V.9). In this month 695 specimens were recorded in a single stomach. Their contribution to the diet decreased in August and increased once more in September.

Bottom sediments found in the stomachs suggest that in April and May A.aquaticus were cropped around the gravelly littoral area, whereas in July, August and September they were eaten in areas of transition between the littoral and bottom muddy area, particularly near the bed line of Potamogeton spp.

Gammarus pulex was more frequent in April (Fig.V.9). At this time they were the third most important benthic invertebrate in trout stomachs. Their contribution decreased from May and they disappeared completely in June. They reappered after July but in low proportions (Fig.V.8).

G. pulex is a very common and abundant organism in the littoral gravely areas. Its contribution to the diet of trout, showing high levels in April and total absence in June, is presumably the result of the feeding behaviour of trout as previously discussed and of the relationship of trout and perch feeding which will be discussed in the next section.

Zooplankton: Daphnia hyalina and Cyclops strenuus were the only zooplanktonic organisms present in trout stomachs the first being the more common (Table V.8). They reached their peak occurrence in April when they appeared in 38.46% of stomachs; in May they were 33.33% and in August 3.57%. Their volume was always low and they were absent in June, July and September (Figs.V.8 and V.9).

Zooplanktonic organisms are usually reported as part the trout diet (e.g. Frost & Brown, 1972). Galbraith (1967) showed that rainbow trout selected larger Daphnia by filtration according to the gill rakers spacing. Frost & Brown (1972), on the other hand, suggested that Bosmina are caught individually.

It is rather surprising that the volume of Daphnia in Cobbinshaw trout stomachs was low in May and that they were absent in June, periods in which this zooplankter reached its highest concentration in the water and when trout were feeding on winged insects at the water surface. Possibly as proposed by Galbraith (1967) the spacing of the trout gill-rakers is too great to allow filtering of the Daphnia. Unfortunately the gill rakers were not measured in this investigation and therefore there is no evidence to support this idea. Nevertheless, it is important to note that during this period predation on zooplankton by perch, particularly those newly-hatched, was very high.

Two others crustaceans were recorded in the trout stomachs: the brachiuran Argulus sp. and the ostracod (Cypris sp.). However their occurrence was negligible.

Arachnida

This class was represented by a few terrestrial spiders and some water mites (Hydrachnellae). Because of their low number and casual occurrence all arachnids were included among 'others' (Table V.8 and Figs. V.8 and V.9).

Perch-fry

These occurred in the stomachs only in June and July. They represented the most important food-item in June appearing in 88.46% of the stomachs (Fig.V.9) and comprising 38.52% of the food volume (Fig.V.8). In July their occurrence had fallen to only 9.09% of the stomachs.

Fish are usually reported from trout stomachs, however there is no rule about the size at which trout become piscivorous. Frost & Brown (1972) stated that in Windermere, trout less than 30cm long seldom ate fish. In Cobbinshaw the smallest trout containing perch-fry in its stomach was a specimen 26cm long.

Nikolsky (1978) pointed out that the growth of fish feeding on fish is faster than that of fish feeding on invertebrates. This suggests that growth of trout in Cobbinshaw might be faster in June as it is at this time that they feed on perch-fry.

The presence of a large number of perch-fry in Cobbinshaw in June is of great importance to the trout population. In this month the trout are probably under stress due to adverse environmental conditions, particularly lowering of the water level, a decrease in the concentration of dissolved oxygen, increase in water temperature to levels higher than the optimum for trout, and blooms of blue-green algae. In such circumstances they feed in the poor black muddy bottom area. However, the presence of perch-fry probably mitigates the situation by allowing the trout to select and concentrate on a single species of prey thus exploiting this transitory but abundant food supply. Furthermore, as trout feed by sight the very active perch-fry become a very attractive and easy prey.

The absence of perch-fry in the trout diet from August onwards is presumably due to their having reached a size which deters trout from feeding on them or having changed their behaviour so that they are less available to the trout .

Stones

Past studies on the feeding habits of trout usually related living organisms to the their diet but did not consider ingested bottom sediments (mud, stones, plant fragments, etc) because of their essentially incidental occurrence and lack of nutritive value. More recently such 'food-items' have been reported (e.g. O'Grady, 1983) as they are occurring more frequently, particularly in the stomachs of trout stocked into lakes where other fish species are already present.

Some unusual food-items, namely stones, pieces of stick and fish food as pellets, were recorded in this investigation. They are considered separately below.

Stones were very frequent in stomach contents in April and May, when they appeared in 34.61% and 36.11% of stomachs respectively (Fig.V.9). The largest volume occurred in April (8.35% of the total volume), followed by May (6.73%)

(Fig.V.8). This was related to the habit of trout of feeding in the littoral area at this time and presumably the stones were ingested accidentally when they caught invertebrates. The size of the ingested stones varied from 0-0.5cm to 2-2.5cm, with a predominance of the former category. In a single stomach 114 stones of 0.1-0.5cm were recorded.

Although stones have been mentioned in the literature as a part of trout food, few works have mentioned the effect of a large amount of stones in the stomach of young trout. Weismann (1984) made a clinical investigation in trout with stones comprising 12.5% of the total body-weight. He found that the fishes showed extremely distended abdomens, their livers had a light brown colour, the intestinal walls were red due to distention of the blood vessels and inflammation. The stones accumulated in the gut as they were not moved by the normal peristalsis and there they caused rupture of the wall permitting nematodes (Cystidicola farionis) to invade the body-cavity and reach the swim-bladder.

The phenomenon of eating stones was attributed by Weismann to an 'irritated behaviour' connected to faults in the 'feeding-technique'.

Plant fragments

A large number of plant remains were observed in trout stomachs all the year round. Their frequency of occurrence reached its maximum value in April when they appeared in 53.85% of the stomachs. It decreased from May (50%) to June (7.69%) and then increased again to reach another peak in September (35.48%) (Fig.V.9).

Plant fragments in March and April were mainly represented by leaves and other debris of plants present in the littoral area. Although they were very frequent in these two months, their contribution to the total volume was comparatively low - 2.70% of the volume in April and 10.67% in May - (Fig.V.8).

After June the plant fragments were mainly represented by pieces of stick from the black muddy area. In August these twigs constituted the main food-item present in the stomach (39.33% of the total volume)(Fig.V.8).

The size of sticks in the stomachs varied from 0.05cm to 4.5-5.0cm. This range of size was also recorded from the lake bottom.

The occurrence of these sticks in Cobbinshaw is due to the presence of old tree-roots and branches on the bottom of the reservoir.

As shown in Plate 5 these pieces of stick often resemble trichopteran larvae cases in shape and colour. They are probably ingested by trout who use sight for hunting, in mistake for such larvae.

The efficacy of artificial flies for angling shows how commonly trout can make such mistakes. Furthermore according to Frost & Brown (1972) 'when no animal is particularly abundant, the stimulus needed to start feeding is likely to be much less specific and the trout will then take any animals which are available more or less at random'.

Fish-food pellets

This is the first record of fish-food pellets from the diet of brown trout stocked in an upland reservoir in Scottish waters.

These food-items occurred at a very low concentration in April (0.52% of the total volume) and were absent in May. In June they were the second commonest food-item (23.11% of the total volume) decreasing abruptly in July (2.3%). In August they rose again to the second place (23.32%) and in September became the major food (42.03%).

The fish pellets consumed by the trout had presumably penetrated through the mesh of rearing cages sited in the reservoir and been deposited below the cages as a consequence of their fast-sinking property and the use of a pendulum feeder.

Possible advantages of adopting this diet of pellets are the easily caught of food-supply and its high nutritive value. Such advantages suggest that trout utilizing pellets shows a better growth rate than that of fish feeding on more 'conventional' food.

Utilization of pieces of stick and fish pellets from June onwards suggests that at this period the trout were forced into bottom-feeding in very poor areas and in their hunting for food they encountered this unusual but abundant food source. Although fish pellets may represent a very nutritive food, feeding on sticks may be disastrous as they have no nutritive value and may damage the gut-wall producing pathological symptoms similar to those caused by stones (Weismann, 1984).

Since perch and pike were not found to have fed on fish pellets, it is probable that their consumption by trout is related to previous experience in the cages.

Besides stones, plant fragments and fish pellets, other items were occasionally observed in trout stomachs such as wires, elastic bands, pins, feathers and cigarette filters. The voracity with which Cobbinshaw trout feed on these unusual objects justifies the words of Dame Juliana Berners (1496) cited in Frost & Brown (1972): 'The trougthe ... he is a right deyntous fyssh and also right fervente-byter'.

V.3.3 **Comparison on the food of perch and brown trout from Cobbinshaw Reservoir**

Figure V.10 shows a comparison between the monthly variation in stomach-fullness of perch and trout. Both species fed intensively from April to September although the percentage of full stomachs observed in perch was higher than in trout. In general perch exploited as food the invertebrates more than trout did. Both species exploited food-items of the same length-range, i.e 0.5-1.0cm, except in June when trout principally selected the 1-1.5cm perch-fry.

Figure V.11 compares the food eaten by perch and trout on a percentage of food volume basis. The important features for each food-item are compared in the following pages and summarized briefly in Table V.9.

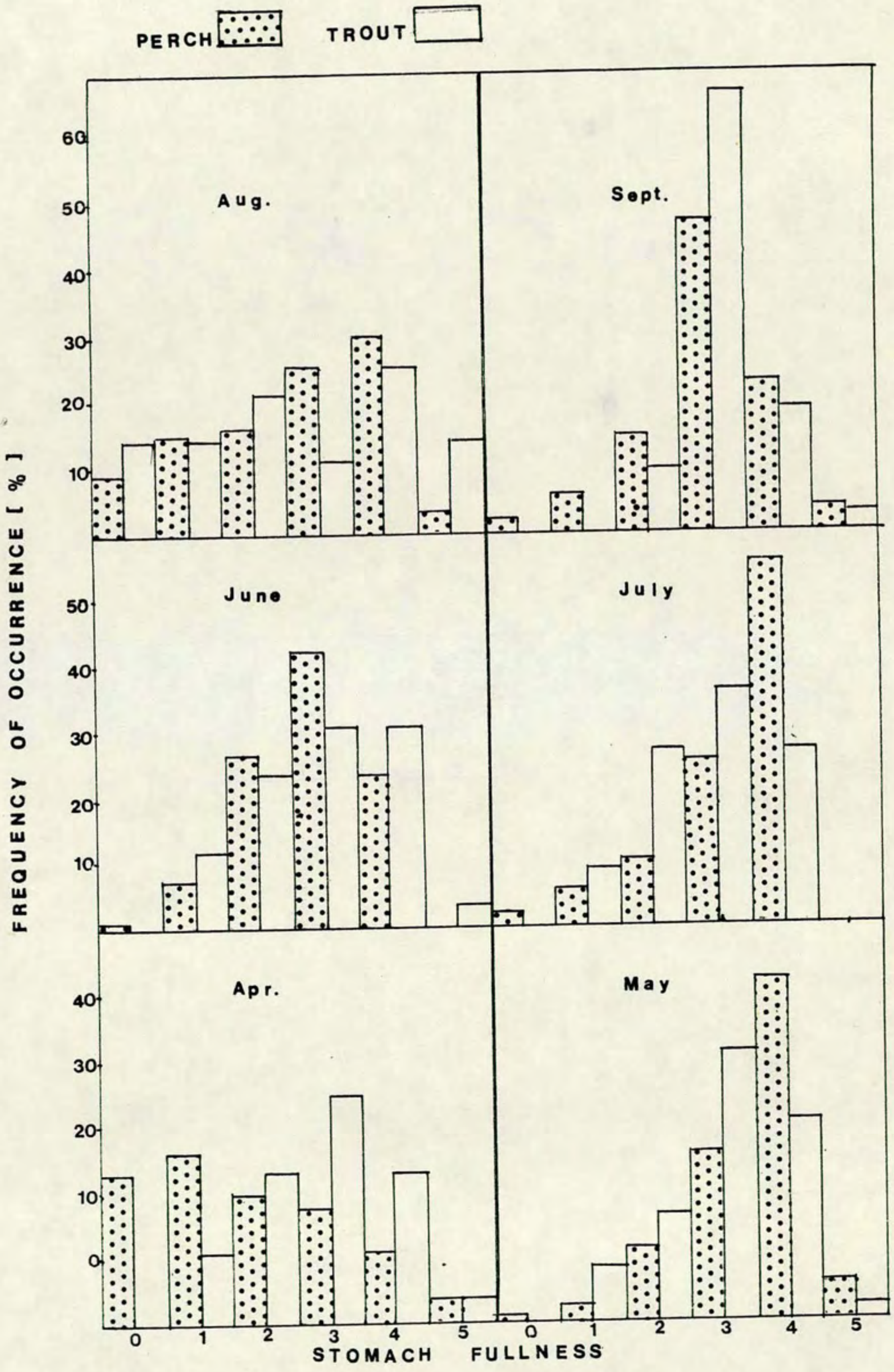


Fig. V.10 - Comparison between monthly variation in stomach-fullness of perch and trout

Table V.9 - Importance of each food-item on the diet of perch, trout and pike. (based on volume of food consumed

	PERCH	TROUT	PIKE
Asellus aquaticus	+++	+++	-
Gammarus pulex	+++	++	-
Trichoptera larvae	-	+++	-
Mollusca	-	++	-
Winged insects	-	+++	-
Zooplankton	+++	+	-
Chir.pupae & larvae	+++	+	-
perch-fry	++	+++	-
Perch adult	-	-	+++
Trout	-	-	+++
Fish pellets	-	+++	-
Sticks	-	+++	-

- rare or absent
+ occasional
++ important
+++ very important

Asellus aquaticus

This crustacean constituted an important food-item for both trout and perch. In April and May it represented more or less the same percentage of the food volume in the stomach of perch and trout and presumably was cropped in the littoral area. In July, however, A. aquaticus was the most important food for trout (42.61% of the food volume) but represented only 8.72% of the food volume in perch (Fig.V.11). Detritus associated with A. aquaticus in the trout stomachs suggested that this prey was cropped in the patch of Potamogeton between the gravelly littoral and the area of muddy bottom.

A. aquaticus is regarded by Thorpe (1974) as the main food used by trout and perch in June in Loch Leven

(Scotland).

Gammarus pulex

This organism constitutes the most important food in the perch diet all the year round but only appeared in trout stomachs in considerable volumes in April (18.87%) (Fig.V.11).

In this context it is interesting to observe that *G. pulex* was a very abundant organism in the littoral all the year round, and that trout are cited in the literature (e.g. Macan, 1963 and Wheeler, 1969) as the main predators of this species.

In Cobbinshaw, however, this is clearly not the case, probably because after April the trout migrate to deeper and colder water where they have no chance to feed on *G. pulex* which is mainly present in the littoral area. Alternatively trout might be excluded from this food source because of intense competition by perch. This possibility is discussed later.

Trichoptera larvae

These organisms occurred very seldom in perch stomachs but they constituted the bulk of trout stomach contents in April and May, the period at which they reached their peak dominance in the bottom fauna (Fig.V.11). It is quite clear that they were not selected by perch but selected by trout.

This is in accord with the results of other studies: trichopteran larvae are usually cited as very rare in perch and very common in trout stomachs. The only exceptional record was that of Campbell (1955) who found these organisms in almost as many perch as trout in Loch Tummel (Scotland).

Mollusca

These organisms constituted an important food-item for trout, but in spite of their abundance they were not used by perch (Fig.V.11). This again agrees with the other studies which found that occurrence of molluscs in perch stomach contents is uncommon whereas they constitute an important food-item for trout (particularly Lymnea pereger (Moriarty,1963)). Moriarty also showed experimentaly that perch dislike Gastropoda. Nevertheless, Burrough & Kennedy (1978) found that Lymnea pereger and Pisidium spp were among the main food-items of both perch and trout in Malham Tarn.

Perch-fry

These organisms represented a high proportion of the contents of trout stomachs (39%) in June as compared with only 7.78% of the food volume in perch stomachs. In July they were reduced to 1.73% in trout and disappeared completely from perch stomachs (Fig.V.11).

Cannibalism in fish is usually described as due to a lack of other food-items (Nikolsky,1978). This is clearly not the case in Cobbinshaw in relation to the perch. Obviously the perch-fry provide a very important food for trout at a time when they are living in an otherwise food deficient area.

Winged insects

Terrestrial and aquatic winged insects were rare in perch stomachs, but constituted a very important food for trout, particularly in May when they were the second most important food (Fig.V.11).

Feeding on surface food is not a common feature in perch but is very common in trout. O'Grady (1983) suggested that stocked trout are usually led to surface feeding because of competition from resident stocks and difficulty in recognizing food invertebrates. This could explain at the same time why Cobbinshaw trout (a)showed such a high preference for winged insects available at the water surface and (b)ingested a substantial amount of bottom detritus.

Zooplankton

Daphnia hyalina was rarely found in trout stomachs but constituted the most important food of perch all the year round with the exception of July (Fig.V.11).

According to Moriarty (1963) zooplanktonic organisms are not common in trout stomach contents in the British Isles, although Southern (1935) recorded the occurrence of the larger Cladocera in Lough Dergh (Ireland) trout.

Chironomid larvae and pupae

Chironomid larvae were very frequent in perch stomach contents although occurring only as a low proportion of the food volume, but were absent from trout stomachs (Fig.V.11).

Chironomid pupae on the other hand were eaten by both species and were more numerous in stomach contents than the larvae. They were found in perch stomachs from May to September, reaching a peak in July, and occurred in trout at the same period as a lower proportion of the food (Fig.V.11).

Others

Arachnida, Annèlida, fish spawn, insect eggs and nymphs were more frequent in perch than in trout. However, in both species they were found only occasionally (Fig.V.11).

Bottom sediments

Plant fragments and fish pellets were not found in perch stomachs. The bottom sediments shown in Figure V.11 represent mainly muddy and some decomposed organic material found in the stomach of perch and trout from April to September.

The parasite Echinorhynchus truttae (Acanthocephala) was present in trout stomachs from April to September. In September these organisms showed the greatest frequency of occurrence appearing in 29% of the stomachs.

According to Frost & Brown (1972), Echinorhynchus has larval stages in crustaceans (particularly Gammarus) and becomes adult in the trout stomach. In the present investigation Echinorhynchus truttae was observed as a parasite of Asellus aquaticus (see Plate 4).

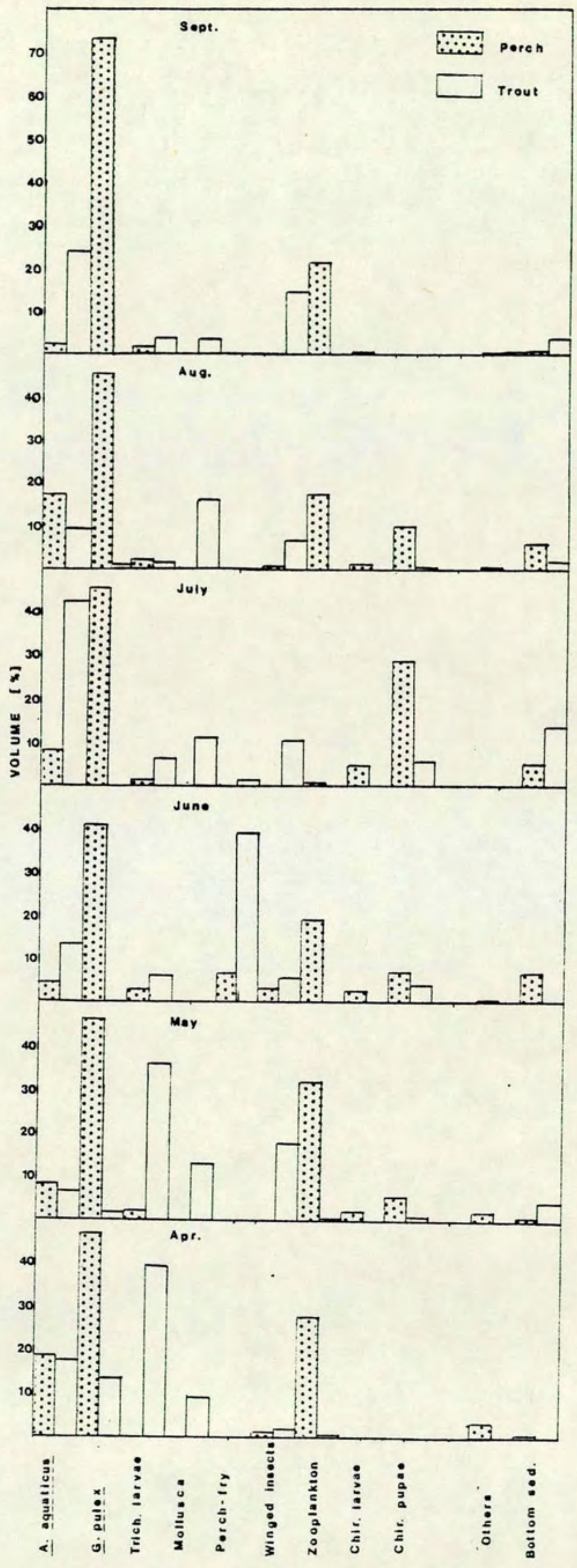


Fig. V.11 - Comparison between the percentage of volume of food eaten by perch and trout

The feeding of perch and trout in Cobbinshaw Reservoir has been compared in the previous pages and is summarized in Table V.9. In General, trout use a wider range of food-items than perch but there is obviously a great overlap in the feeding of the two species, although it is difficult to know if competition actually occurs. In fact, as pointed out by Nilsson (1967), consideration of competition is usually accompanied by controversy and semantic discussion. Therefore, definition of the term competition in this instance is necessary.

Birch (1957) considered that `competition occurs when a number of common organisms (of the same or different species) utilize common resources that are in short supply, or if resources are not in short supply competition occurs when organisms seeking that resource harm one another in the process'. Weatherley (1972) discussed the different definitions of competition given in the literature and showed how it is difficult to define and to observe competition.

Competition can occur for food and space. The present investigation showed that the littoral area of Cobbinshaw Reservoir is a very rich food source and, presumably, shortage of food could not be a cause of competition between perch and trout. Furthermore, as shown by Larkin (1956), even in the presence of a short supply other factors such as patterns and time of feeding and habitat position must be considered before competition can be shown to exist. Unfortunately such factors were not investigated. I would recommend this as an important aspect to be investigated in Cobbinshaw Reservoir in the future.

As shown in Fig. V.11, Asellus aquaticus was consumed by both perch and trout all the year round. Nevertheless, this does not mean that competition for A. aquaticus is actually occurring. In fact, as suggested by Hynes (1970), similarity of diet usualy indicates a non-competitive interaction between the co-existing species . Keast (1978) referred to the overlap of diet as a result of the low number of species found in the community.

Another aspect supporting the idea of no competition between perch and trout in Cobbinshaw Reservoir is the fact that the growth of perch is very fast and according to Weatherley (1972) fish tend to grow rapidly when food and or space are plentiful and slowly when either or both are scarce. Unfortunately, there is no information on the growth of trout which could be used as additional evidence for this. This aspect also needs to be investigated.

Although this study has provided no firm evidence to support the contention that competition between perch and trout occurs in Cobbinshaw Reservoir the following points as, however, worthy of mention.

From June to August trout almost cease feeding on Gammarus pulex. The literature, however, shows that this species constitute the main food item for trout in many waters (Macan, 1963 and Wheeler,1969). Perch, on the other hand, fed intensively on G. pulex during this period, which suggests that the perch are preventing the trout from feeding on *G. pulex*. However, this could be caused by trout migrating to avoid high water temperature from the littoral and shallow-water, where *G. pulex* abounds, to deeper water, rather than by any competition between these species. Ball & Jones (1961) observed the same migratory behaviour in brown trout in Llyn Tegid (Wales), where the trout left the littoral area when the temperature reached 12°C. Nevertheless, this hypothesis is rejected when switching of trout is accounted for, particularly in the evening when the water temperature drops and they could move to the littoral area in order to feed.

In this context is interesting to refer to the work of Hynes (1970) who suggested that any observed change in the diet caused by the presence of another species would indicate competition for food. In fact, feeding behaviour of trout and perch in Cobbinshaw Reservoir could be a consequence of separation of both species into different niches as proposed in the principle of interactive segregation (Nilsson,1967). The term interactive segregation means that `ecological differences between species ((e.g., in food or habitat selection) are often magnified by interaction, i.e., the species segregate into different niches due to competition and or predation.

It may be possible that the trout in Cobbinshaw change their feeding behaviour according to perch movements, i.e., when the perch are in deep water they move inshore and vice-versa. Thus, when the perch are feeding intensively in the littoral area, the trout either hunt surface food not used by the perch or feed on the bottom. As the bottom fauna is very poor and it is difficult to recognize many benthic invertebrates (O'Grady, 1983) they feed on pieces of stick, confused with the cases of caddis larvae, and on fish pellets due to their previous experience in the cages.

According to Nilsson (1967) there are five possible mechanisms in the segregation process: 1) exploitation occurs when one species can find and use the resource more easily and quickly than the other; 2) territoriality which leads the fish to defend its own area; 3) food fighting which consists in agonistic activity occurring in relation to feeding; 4) predation and 5) interference, which implies a directly harmful effect.The present investigation shows no evidence to support the hypothesis that any of the mentioned mechanisms are occurring in Cobbinshaw Reservoir. Actually, this work was carried out to investigate the availability of food and its importance on the feeding habits of perch and trout. Nevertheless, it leads one to conclude that, although it is unlikely that food supply is a problem for perch and trout in Cobbinshaw Reservoir, it is clear that future investigation on the segregative interaction between these species is necessary before any conclusion could be drawn about their feeding interaction.

V.3.4 The food of pike from Cobbinshaw Reservoir

Appendix 1 shows the records of the pike taken from Cobbinshaw Reservoir, by the angling club suggesting that the population is decreasing. In fact during the present investigation only 57 pike were caught although various fishing methods were used (seine net, gill net, traps and angling). The mean length of these fish was 37.8 cm ($\pm$ 10.9 S.D.) and the range varied from 13.3 to 64.0 cm.

The stomach contents of these 57 pike were analysed following the methods described for trout and perch in the material and methods section. It was observed that 24.56% of the stomachs were full of which 17.54% were distended because they contained two-year-old trout. The percentage of empty stomachs was 17.55% and they occurred most frequently in April, presumably because of spawning peak.

Table V.10 shows the frequency of occurrence of food-items and the percentage of volume they represented.

Table V.10 - Variation on the frequency of occurrence of food-items of pike and the percentage of volume they represented.

	FREQUENCY OF OCCURRENCE (%)	VOLUME (%)
Asellus aquaticus	45.61	0.660
Gammarus pulex	42.10	0.290
Trichoptera larvae	14.03	0.040
Chir. larvae	7.02	0.001
Potamopyrgus jenkinsi	15.79	0.003
perch-fry	5.26	0.050
Perch adult	17.54	12.470
Trout adult	19.30	86.370
Others	1.75	0.000
Plant fragments	17.54	0.003
Stones	14.03	0.004
Bottom sediments	8.77	0.030

Asellus aquaticus was the food organism most frequently recorded, occurring in 45.61% of the stomachs and was followed by Gammarus pulex (42.1%) - however, because of their small size these items only constituted 0.66% and 0.29% respectively of the total food volume.

Perch occurred in 22.8% of the stomachs and trout in 17.54%, while other organism such as Potamopyrgus jenkinsi (15.79%), trichopteran larvae (14.03%) and chironomid larvae (7.02%) occurred in smaller quantities.

Plant fragments, stones and bottom sediments appeared in, respectively, 17.54%, 14.03% and 8.77% of stomachs.

As shown in Table V.10 trout were by far the most important food-item and represented the bulk of the stomach contents (86.37% of the total volume). They were followed by perch (12.47%). All the other food-items lumped together repesented only 1.11% of the total volume.

Although only 57 pike were examined it is clear that trout constitute their principal food, followed by perch. Although a variety of other smaller food-items are ingested they provide a negligible proportion of the diet.

The feeding of perch, trout and pike in Cobbinshaw Reservoir has been compared and is summarized in Table V.9 (page 223).

VI. CONSIDERATIONS ON FUTURE MANAGEMENT AND RESEARCH

This investigation has not demonstrated any competition between perch and trout although the policy of controlling perch numbers in the reservoir is based on the supposition that it occurs. In the future it might be interesting to see if a period in which there was no attempt to control perch numbers actually had an effect on trout catches.

Consideration might also be given to the establishment of a small commercial perch fishery to provide money for trout-stocking. The first step in this direction has actually been taken; and perch are at present being sold to fishmongers by the Club. However, the top lake has not been exploited for this purpose and the analyses of a few perch from this lake suggested that the growth there is better than in the lower lake.

Another very important aspect to be considered is the possibility of augmenting the productive littoral zone, or at least attempting to diminish its reduction in summer . The former might be achieved by introducing more stones and gravel further from the shoreline and thus extending the littoral band. The latter would require negotiation with the British Waterways Board to see if there would be any possibility of their keeping the level of the reservoir more stable.

Information supplied by anglers suggests that the weed beds are spreading steadily from year to year. Therefore it will be necessary to carry out investigations to find out if they are affecting trout movement and feeding and if it is desirable to control them.

In this context it is interesting to observe that the beds of *Equisetum palustre* are being much exploited by *Potamopyrgus jenkinsi* - a food considered of low nutritive value and not very common in the trout diet.

The presence of a high volume of fish pellets in trout stomachs demonstrates that a large amount of food is passing through the meshes of the cages and is deposited under the bottom of the cages, probably as a consequence of their fast-sinking behaviour. From an economic point of view this could represent a considerable increase in the cost of trout production. This problem could be solved by using slow-sinking pellets especially recommended for cage systems. However, according to the manufacturers of the pellets used in Cobbinshaw Reservoir (Edward Baker-Omega), the fast-sinking pellets are more efficient in food conversion because of their high energy content and this reduces the cost per kilo of trout produced. Furthermore, it seems that the lost pellets are in any case converted into fish rather than rotting on the bottom of the lake. Such observations suggest that it is necessary to carry out a detailed investigation to decide which is the best feeder system for Cobbinshaw, particularly bearing in mind the importance of water temperature on feeding activity.

It was observed that a considerable number of trout died in the rearing cages during the summer, particularly in June. As suggested by Jarrams et al (1980), water for rearing trout in cages should not be subject to excessively high summer temperatures or experience algal blooms'. Such conditions associated with decreases in dissolved oxygen are presumably the main factors causing the death of trout in the Cobbinshaw cages. In this context further investigations are obviously desirable and should give information on when would be the best time to release the trout from the cages.

It is also necessary to account for the possible eutrophication of the lake as a result of waste organic products from these cages. In fact, deposition of fish feces and pellets under the cages may contribute to the mesotrophic condition which characterizes Cobbinshaw Reservoir today. Therefore, it is suggested that some assessment should be made of this situation with a view to limiting the number of cages sited in the reservoir.

VII. SUMMARY

1) The present investigation dealt with studies of some aspects of the population of perch (Perca fluviatilis L.) from Cobbinshaw Reservoir, particularly age, growth, food, and feeding interaction between this species and brown trout (Salmo trutta) - a fish which has been stocked in the lake since 1906. It repesents the first survey on this subject carried out in Scotland.

2) Investigations were carried out to determine the physico-chemical characteristics of the lake.

It was observed that the lake substrate was represented by a small littoral gravelly area with a large number of potential fish diet invertebrates considered very poor.

The water temperature varied from 'freezing point' in the winter to relatively higher temperatures (26°C) in June. Dissolved oxygen concentrations were highest in the spring but remained at levels suitable for trout, perch and pike all the year round. pH varied from 7.2 to 8.5 and the water was classified as soft with an alkalinity (maximum 50ppm) below the level considered optimum for trout growth.

The water level varied during the year and reached its lowest level in June, when part of the littoral area was exposed.

Physico-chemical analyses were also extended to light penetration, turbidity, nitrogen, phosphate and silica levels.

3) Assessment of plankton and bottom fauna was carried out

by estimating seasonal abundance, size and distribution of these organisms in order to relate them to the feeding habits of perch and trout.

Among the most abundant zooplanktonic organisms were Daphnia hyalina and Cyclops strenuus. The bottom fauna was dominated by Gammarus pulex, Asellus aquaticus, Pisidium sp, Lymnea pereger and Potamopyrgus jenkinsi. Trichopteran larvae and chironomid larvae and pupae were also abundant.

4) Fish were collected using seine nets, gill nets and traps and comments on the fish sampling are presented in Chapter IV. The population of perch from Cobbinshaw Reservoir was characterized by a large number of individuals between four-and six-years-old. The oldest fish recorded was nine-years-old.

The sex ratio observed in the total sample was 1.2 males:1.0 female.

Very fast growth occurred until the fourth year after which the ratio decreased. The dominant length-class ranged from 20-23cm, which includes fish from three-to nine-years-old.

Growth of Cobbinshaw Reservoir perch was considered very good when compared with growth of perch in other British waters. The greatest growth increment occurred during June and July.

It was observed that the rate of growth decreased steadily with age and followed the von Bertalanffy model.

Values of condition factor K were calculated and it was observed that the perch are in a very good condition.

The mathematical length-weight relationship showed the occurrence of allometric growth.

5) Studies on the food of perch showed that they fed mainly on Gammarus pulex, Asellus aquaticus, chironomid larvae and pupae and zooplankton (particularly Daphnia hyalina).

Low feeding intensity in April, with the incidence of the largest number of empty stomachs recorded, suggested decreased feeding during the peak of spawning. Apparently this is compensated for by very intense feeding in May.

6) Trout exploited many of the same foods organisms as perch. Trichopteran larvae, winged insects and Mollusca were particularly important for them but were rarely eaten by perch. In July perch-fry were an extremely important part of their diet. Unusual food-items namely pieces of stick (Presumably ingested in mistake for trichopteran larvae) and fish pellets were recorded after June.

7)Differences between the food of trout and perch suggest that a segregative interaction might be occurring. However, stocked trout often show atypical behaviour and this study has provided no firm evidence to support the contention that competition between perch and trout is actually occurring in Cobbinshaw Reservoir.

8) The food of pike consisted of trout and perch, with the former being the most important (86.37% of the total volume of food). A number of other food-items (particularly Asellus and Gammarus) were taken but they represented a negligible volume of the total food. Clearly pike, as a voracious predator of trout, are undesirable in Cobbinshaw Reservoir.

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Appendix 1. - Numbers of trout, pike and perch caught in Cobbinshaw Reservoir since 1906.

Year	Trout	Pike	Perch
1906	1	337	-
1907	253	719	-
1908	-	-	-
1909	408	79	-
1910	1685	-	-
1911	1734	-	-
1912	1475	-	-
1913	951	-	-
1914	1027	36	-
1915	1201	90	-
1916	638	-	-
1917	452	92	-
1918	963	350	-
1919	759	49	-
1920	460	69	-
1921	348	72	-
1922	387	121	-
1923	419	32	50
1924	583	128	-
1925	503	180	55
1926	274	151	3
1927	1590	206	-
1928	1180	94	38
1929	613	269	965
1930	1045	115	1568
1931	1509	77	1557
1932	2297	58	-
1933	1283	139	370
1934	1450	197	41
1935	2099	193	132
1936	2229	107	300
1937	2099	212	800
1938	1287	125	200
1939	1086	206	250
1940	792	339	331
1941	1071	115	400
1942	1791	99	600
1943	749	84	1700
1944	1380	35	700
1945	1014	86	570
1946	672	131	2800
1947	366	464	3900
1948	135	75	157
1949	943	288	-
1950	947	145	6151
1951	1365	45	1726
1952	2180	128	6368
1953	2932	85	2310
1954	2269	40	806

Cont'd

Year	Trout	Pike	Perch
1955	2151	99	1510
1956	2961	117	187
1957	2340	53	870
1958	2653	56	758
1959	2188	316	2851
1960	1826	383	1381
1961	2280	190	832
1962	1498	170	527
1963	2083	216	357
1964	1567	130	230
1965	2074	75	295
1966	1237	211	661
1967	1211	186	976
1968	542	125	1190
1969	36	80	5930
1970	1437	84	1480
1971	2678	51	870
1972	1684	84	930
1973	2468	51	630
1974	1974	27	560
1975	1887	-	-
1976	2860	-	-
1977	1918	-	-
1978	2083	-	-
1979	2521	170	3475
1980	3154	196	4308
1981	4261	56	1905
1982	4098	43	3120
1983	4500	32	6100

Source of data: Cobbinshaw Angling Association fishing log book and Mr. J.M.Burns (personal communication).

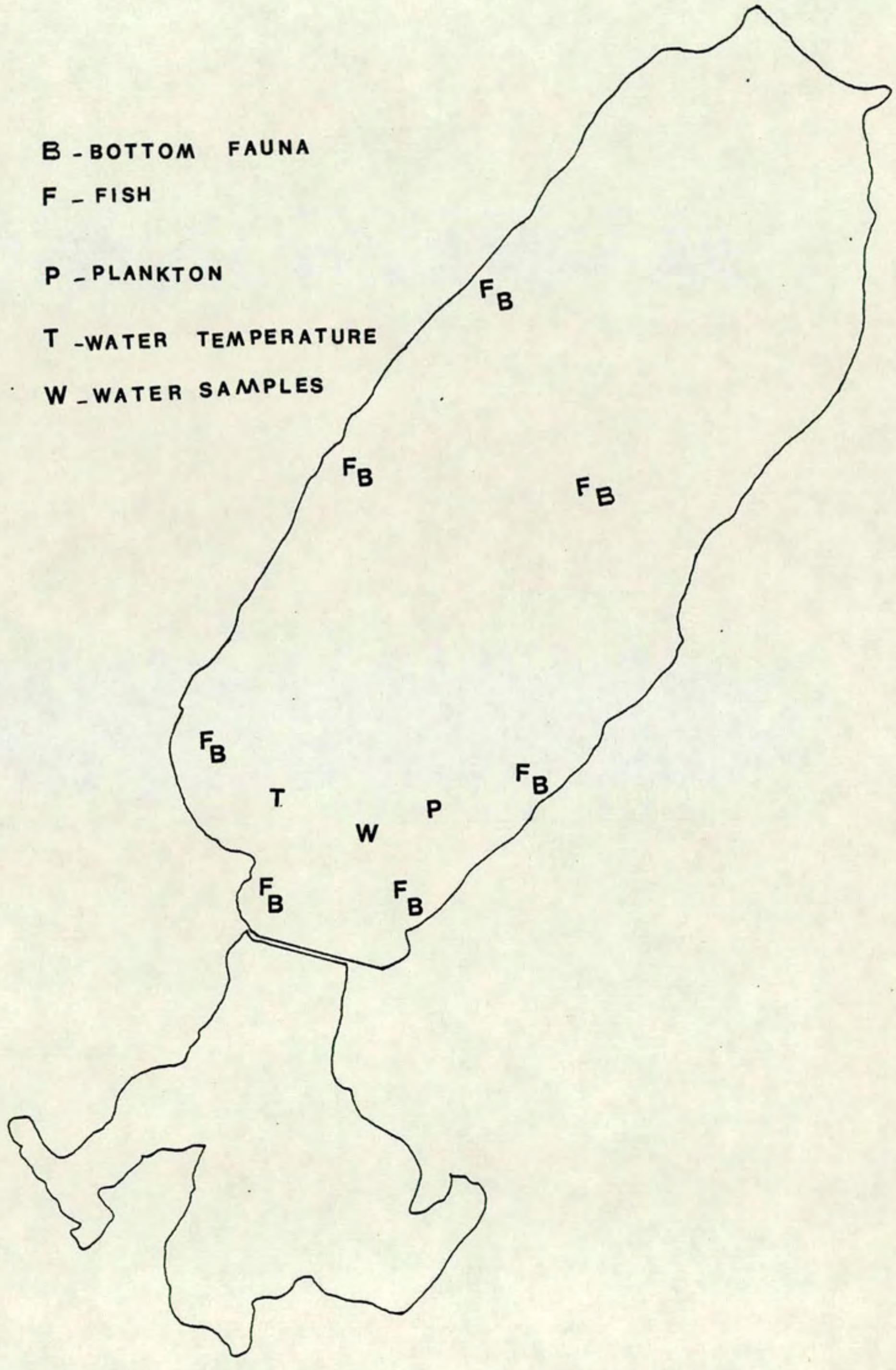
Appendix 2. - Montlhy variation of water temperature and dissolved oxygen in different depths.

DATE	DEPTH	TEMPERATURE(^{o}C)	DISSOLVED OXYGEN(ppm)
18/02/82	Surface	3.0	11.0
	1m	3.5	10.5
	2m	4.0	10.0
	3m	4.0	10.0
	4m	4.0	10.0
18/03/82	Surface	3.5	12.0
	1m	3.5	11.0
	2m	4.0	10.5
	3m	4.0	10.5
	4m	4.0	10.0
	5m	4.0	10.0
18/04/82	Surface	11.5	13.5
	1m	11.0	13.5
	2m	10.5	13.0
	3m	10.5	12.5
	4m	10.0	12.5
18/05/82	Surface	16.0	12.5
	1m	15.0	11.0
	2m	14.5	11.0
	3m	14.5	10.5
	4m	14.0	10.0
18/06/82	Surface	19.0	10.0
	1m	18.0	9.0
	2m	17.5	8.5
	3m	17.0	8.5
	4m	17.0	8.0
18/07/82	Surface	17.5	10.0
	1m	16.5	9.5
	2m	16.0	8.5
	3m	16.0	8.5
	4m	15.5	8.0
18/08/82	Surface	15.0	11.0
	1m	14.0	11.0
	2m	13.5	10.5
	3m	13.0	10.0
	4m	13.0	10.0
18/09/82	Surface	13.0	11.0
	1m	12.5	11.0
	2m	12.0	10.0
	3m	12.0	9.0
	4m	12.0	9.0
18/10/82	Surface	8.5	10.0
	1m	8.0	10.0
	2m	8.0	10.0
	3m	8.0	10.0
	4m	8.0	9.0
18/11/82	Surface	5.5	11.0
	1m	5.0	11.0
	2m	5.0	11.0
	3m	5.0	11.0
	4m	5.0	10.0

Appendix 3. - Winged insects found in trout stomachs

Order	Family	Species
Heteroptera	Corixidae	Corixa faleni and one sp. unindentified
Heteroptera	Pleidae	Plea atomaris
Heteroptera	Miridae	one sp. unindentified
Hemiptera	Cicadellidae	Macropsis spp.
Hemiptera	Delphacidae	Delphax spp.
Hemiptera	Aphididae	three spp. unindentified
Hemiptera	Cercopidae	One sp. unindentified
Hemiptera	Psyllidae	One sp. unindentified
Plecoptera	Neumoridae	One sp. unindentified
	Perlidae	One sp. unindentified
Neuroptera	Sialidae	Sialis luraria
Trichoptera	Limnephilidae	Limnephilus sp.
Lepidoptera		One unindentified moth
Diptera	Mycetophilidae	Five spp. unindentified
	Chironomidae	One sp. unindentified
	Anisopodidae	One sp. unindentified
	Cecidomyidae	One sp. unindentified
	Tipulidae	One sp. unindentified
	Asilidae	One sp. unindentified
	Empididae	Two spp. unindentified
	Dolichopodidae	One sp. unindentified
	Conopidae	One sp. unindentified
	Sepsidae	One sp. unindentified
	Muscidae	Three spp. unindentified
	Syrphidae	One sp. unindentified
	Drosophilidae	One sp. unindentified
Coleoptera	Hydrophilidae	Hydrobius sp.
	Staphilinidae	Four spp. unindentified
	Dysticidae	Dytiscus spp, Platambus maculatus
	Coccinelidae	Two spp. unindentified
	Cerambycidae	Two spp. unindentified
	Scarabeidae	One sp. unindentified
	Carabidae	Amara aulica and one sp. unindentified
	Haliplidae	One sp. unindentified
	Chrysomelidae	One sp. unindentified
	Curculionidae	One sp. unindentified
Hymenoptera	Ichneumonidae	Three spp. unindentified
	Tenthredinidae	Four spp. unindentified
	Braconidae	Apanteles glomeratus and one sp. unindentified
	Sphecidae	Two spp. unindentified
	Cephidae	One sp. unindentified
	Formicidae	Formica rufa
	Platygasteridae	One sp. unindentified
	Cynipidae	One sp. unindentified
	Pteromalidae	One sp. unindentified

Appendix 4 - Map of Cobbinshaw Reservoir showing sampling areas



Appendix 5 - Mean length and range of examined fish.

Month	No. of fish examined	Range (cm)	Mean length ± S.D.
MARCH	52	9.6-25.2	19.1±4.3
APRIL	58	8.8-26.9	22.4±1.3
MAY	84	8.5-24.4	21.8±1.3
JUNE	82	8.4-24.3	19.6±3.9
JULY	78	5.5-26.4	17.6±4.1
AUGUST	94	7.5-24.6	20.6±2.6
SEPTEMBER	76	5.5-24.9	21.4±2.9
OCTOBER	60	4.4-24.5	20.3±4.2

PLATE 1 . Exposed area of the littoral in the summer.
a) Equisetum palustre b) Potamogeton spp

PLATE 2 . Perch from Cobbinshaw Reservoir at age intervals of one year from one to seven-years-old.

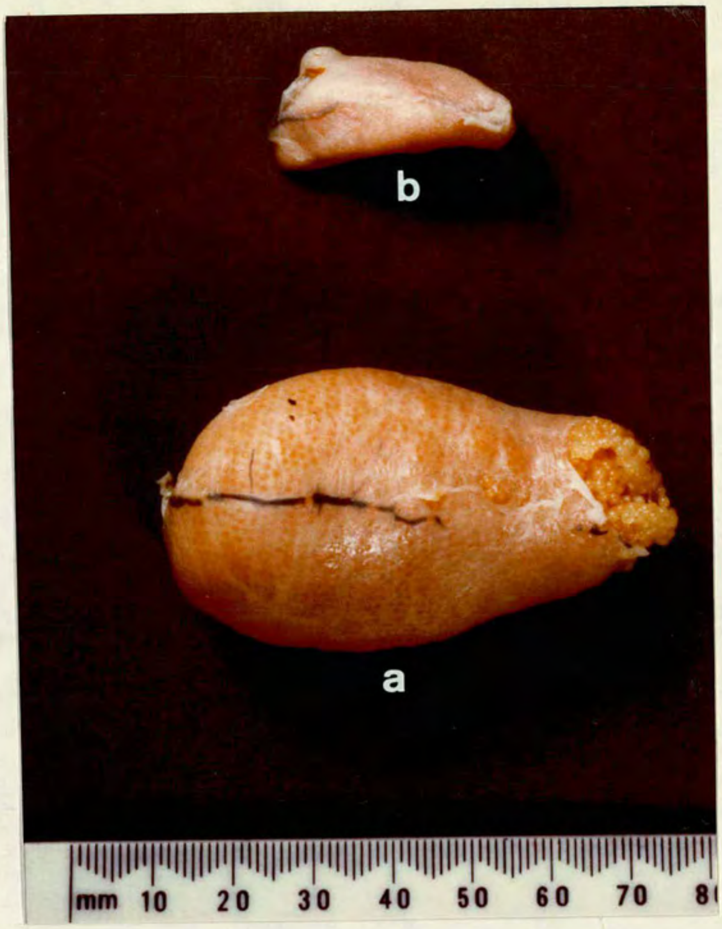


PLATE 3 . Ovary of a 4-year-old perch.
a) April b) July

PLATE 4 . Asellus aquaticus parasitized by Acanthocephala from a perch stomach.

PLATE 5 . Sticks from the stomach of a single trout.